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Spectral Analysis of the Human Body Sway during Standing on Firm and Compliant Surfaces under Different Visual Conditions

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Abstract—Effects of different visual conditions on the vertical posture maintenance were compared in subjects standing on a firm or compliant surface. These visual conditions included a motionless visual environment (MVE), eyes-closed condition (EC), and a virtual visual environment (VVE). The VVE consisted of two planes: the foreground and background. The foreground displayed a room window with adjacent walls, and the background was represented by an aqueduct with the adjacent landscape. The VVE was destabilized by inducing either the cophased or the antiphased relation between the foreground of the visual scene and the body sway. We evaluated changes in the amplitude spectra of two elementary variables calculated from the trajectories of the plantar center of pressure (CoP) displacements in the anteroposterior and lateral directions, namely, the trajectories for the center of gravity projections on the support (the CG variable) and the differences between the CoP and CG trajectories (the CoP–CG variable).The CG trajectory was considered as a controlled variable, and the difference between the CoP and CG trajectories were considered as a variable related to the body acceleration and reflecting changes in the resultant stiffness in ankle joints. The root-mean-square (*RMS*) values for the spectra of both variables calculated from the body sway in the anteroposterior direction in standing on a firm support decreased proportionately with antiphased relation between the foreground and the body sway and increased with the cophased relation, compared with the *RMS* calculated for the MVE conditions. *RMS* for the spectra of the CG variable in the cophased relation were nearly the same, as in standing with eyes closed (EC), while the *RMS* for the spectra of the CoP–CG variable were significantly less than with EC. The body sway during standing on a compliant support significantly increased in both the anteroposterior and the lateral directions under all visual conditions. *RMS* for the spectra of both variables with EC increased considerably higher than in the cophased relation. Furthermore, the *RMS* for the spectra of the CG variable calculated from the body sway in the lateral direction on a compliant support was substantially higher in the antiphased relation than in the cophased relation, whereas the *RMS* for the spectra of the CoP–CG variable under both conditions had similar values. The analysis of body sway and the results under some visual conditions have shown that the amplitude characteristics of the CG and CoP–CG variables changed not always proportionately with the passage from standing on a firm support to a compliant support. It is suggested that the found disproportion of changes in these two variables is probably associated with the contribution of another additional factor to the process of postural control, the passive elastic component of musculo-articular stiffness generated by fascial-tendon tissues.

Keywords: vertical posture, visual effects, spectral characteristics of body sway, virtual 3D environment

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A human vertical posture is naturally unstable, due to the high position of the center of gravity (CG) relative to the support and the body multisegment structure. Small deviations from the suitability of the body vertical position lead to the emergence of spin momentum due to the force of gravity. The latter acts on the body and makes it to deviate still farther from its vertical posture, but muscular corrective responses secure the recovery of verticality by the body. The process of triggering muscle responses to counterbalance the natural postural instability and generate the postural correction forces are so far quite unclear, as is the mechanism underlying interactions between the sensory and locomotor systems in this process [1, 2]. Nevertheless, the human central nervous system (CNS) successfully solves the posture maintenance problem in the majority of cases, coordinating the muscular activity of the legs and body by the information coming from the vestibular, proprioceptive, and visual sensory systems [1–4].

Regarding visual information, its presence is not compulsory for the vertical posture maintenance, although switching off vision considerably deteriorates the quality of standing [5–9]. The visual system participates in solving the postural stabilization problem, using different mechanisms. On the one hand, vision directly participates in the assessment of the value, rate, and direction of body sway [10–13], using the mechanisms of feedback and feedforward control [14]. On the other hand, vision can nonspecifically affect the postural regulation system. This is indicated, in particular, by the fact that closing the eyes in darkness, when vision cannot be useful for postural stabilization, may lead to further deterioration in the quality of standing [15]. On the contrary, opening the eyes in full darkness leads to a better posture maintenance, compared with standing with eyes closed [16]. These and other observations have allowed some authors to suggest [17–20] that visual effects, including nonspecific ones, are mainly realized through the regulation of musculo-articular stiffness (primarily, in the joints of lower limbs) and mediated by changes either in the levels of tonic contraction in the corresponding postural muscles or in the level of the amplification coefficients in the vestibular and/or proprioceptive subsystems of postural regulation. The results reported by these studies merely indirectly confirmed the mentioned suggestion. For example, evaluating postural responses to vestibular stimulation in standing with the eyes open and closed (EO and EC, respectively), Fitzpatrick et al. [19] have found that the span of the body background sway and the value of responses to a stimulation proportionately increase under the EC conditions, which is interpreted as a nonspecific EC effect on muscular stiffness.

We attempted in our study to determine whether the principle of proportionality between changes in musculo-articular stiffness and the body sway is preserved against the background of more integrated visual stimuli acting on a vertical posture under more complex conditions.

We used the EC condition and three conditions of "immersion" into a virtual visual environment as the visual conditions when visual environment was either motionless or nonstationary due to the inclusion of cophased (CR) or antiphased relation (AR) between the environment and the body sway. The compliant support was selected based on the results of our earlier study [21], in which we showed that, during posture maintenance on such a support, under the conditions of motionless visual environment the relative contribution of elementary variables was somewhat different from that on a firm support.

We evaluated changes in the spectra of two elementary variables estimated from the plantar center of pressure (CoP) displacements. The first variable described displacements of the vertical projection of the body CG (CG variable) and was a controlled value [22, 23], while the second one was the difference between the plantar CoP and CG (the CoP–CG variable), which allowed us to judge the changes in the resultant musculo- articular stiffness in the ankle joints [22–25].

METHODS

Fourteen apparently healthy subjects, including eight men (with the mean age of 42.6 ± 5.6 years) and six women (with the mean age of 44.0 ± 6.2 years), without visual pathology or a history of any neurological disease, participated in the study. They were previously informed about the content and procedure of the experiments and gave their written consent to the participation in the study. The subjects had to keep a comfortable vertical posture during tests, standing on the square platform of a stabilograph (40 × 40 cm, Stabiloplatforma-2, Design Bureau, Research Engineering Institute (RII), Balashikha, Russia), by which the changes in the position of the plantar CoP on the support were recorded. The subject's feet were in a comfortable position and were turned towards each other at an angle of 20–30 degrees, while the distance between the heels was 6–8 cm.

Trying to maintain their vertical posture, the subjects were looking at the screen (1.5 m high and 2 m wide), made of a fabric minimally depolarizing the falling light (the silverscreen). Using the so-called passive technique [26], a 3D stereoscopic image based on the light-induced polarization effect was generated on the screen. In particular, two images of the same scene—a window view on an aqueduct—were simultaneously projected on the screen with two projectors (Sharp XR-10X), supplied with polarized filters and orthogonally oriented relative to each other. The subjects and the projectors were located on the same side relative to the screen. During the tests, the subjects wore glasses with 3DS-GS (Panorama) polarizing filters (Stel—Computer Systems, Moscow) with the interleaving rate of 120 Hz, oriented in parallel to the corresponding filters of projectors, which provided 3D perception. The field of view (FoV) of the subjects was limited by the glasses at about 60° vertically and 80° horizontally and did not go beyond the screen limits. Due to these limitations, the subjects could see only a virtual 3D picture, which included two planes. The first plane was a window of a room with adjacent walls, while the second one was an aqueduct with its surrounding locality. The distance of the foreground image from the subject was 1.2 m, while the second (background) plane was at a distance of 20 m. Thus, subjects could orient themselves only within the presented VVE. During testing the posture maintenance, subjects were asked to look at the static background, approximately at the center of the screen and use it as the reference system element.

To study the vertical posture maintenance in the VVE displacements, which are cophasally and antiphasally related to body sway, we used the technique of a more complete "immersion" of subjects into virtual reality. For this purpose, the foreground position of VVE in the lateral and anteroposterior directions made the CoP dependent on low-frequency (below 1 Hz) fluctuations in the corresponding planes. Such an attribution (relation) led to a situation when foreground deviations of VVE took place almost simultaneously (with a delay of 25 ms) with the body sway.

The relation of the VVE foreground with body sway allowed the experimenter to set, prior to each test, the direction (antiphased or cophased) of VVE foreground deviations. In this study, the coefficient of relation between the VVE foreground deviations and the body sway was equal to 2; i.e., if the body deviated in the anteroposterior direction, e.g., to 1 cm, the VVE foreground deviated to 2 cm. We showed earlier that the subjects who corrected their postures under such conditions involuntarily used the mobile VVE foreground as a baseline to set up a reference system, and, thus, destabilized their postures, compared to the normal visual conditions [8]. The manipulation with the direction of relation between the body sway and VVE led to a situation when the subjects, according to their verbal reports, perceived the outer environment, on the whole, as nonstationary, despite the presence of the static background.

The CoP trajectory derived with the stabilograph pressure sensors was converted from the analogue form into the digital one at a sampling rate of 100 Hz and then saved to a PC. In subsequent analysis, this trajectory was deployed as a sum of two time-related functions along each (lateral and anteroposterior) axis. The vertical posture maintenance was assessed by analyzing changes in the amplitude–frequency characteristics of two elementary variables calculated from the CoP movements on the support. One of the two was the vertical CG projection trajectory (CG variable), while the other trajectory was the difference between the CoP and CG trajectories (the CoP–CG variable). We used the approach suggested in the study [27] and described in detail and used in a series of studies [23, 25, 28] for the calculation of these trajectories. Therefore, only the main principles of this approach are described below.

The method for the estimation of the indicated elementary variables is based on the idea that there is a clear dependence of changes in the amplitude of CG and CoP displacements on the frequency of fluctuations. In particular, it has been shown [23, 24, 27] that the ratio between the amplitudes of these variables (CG/CoP) is the highest, approximating 1.0, at the minimum fluctuation frequencies (close to 0.0 Hz) and the lowest, approximating 0.0, at the maximum frequencies (above 3 Hz). It is easy to conclude that the relatively high-frequency CoP fluctuations did not affect the value of CG fluctuations. Actually, as was experimentally shown in the cited studies, the CoP fluctuations at frequencies of above 0.5 Hz were not, in fact, reflected on the value of CG fluctuations. Proceeding from this understanding, we used the low-frequency filtration method expressing the ratio between the amplitudes of CG and CoP fluctuations and reflecting the relation between the CoP fluctuation frequency and body sway to derive elementary variables [23, 25, 27]. Subsequently, analyzing the experimental results, the CG movements were considered as a controlled variable, while the CoP–CG difference, as a variable related to the body acceleration and reflecting changes in the resultant musculo-articular stiffness in ankle joints [22, 23, 25]. The effect of visual conditions on the process of vertical posture maintenance was assessed, analyzing changes in the median frequency (*MF*) and root-mean-square value (*RMS*) of the amplitude spectra within 0–0.5 Hz for the CG variable and 0–3.0 Hz for the CoP–CG variable.

The program for the CoP fluctuation frequency filtration to distinguish CG and CoP–CG variables and their subsequent estimation, based on the *MF* and *RMS* of fluctuation spectra, was written in the Matlab environment.

The subjects were instructed during testing the process of posture maintenance: **"Choose a small fragment of the aqueduct at the eye level on the background and look at this fragment during test performance,"** minimizing the body sway as much as possible. CR or AR between the visual environment and body sway in individual tests were set up at random. The tests with the adjustment of the VVE foreground to the body sway alternated with the tests in MVE and tests with the visual control completely suspended (EC condition). Under the MVE conditions, the subjects were standing in the same stereoscopic glasses, and the FoV was limited by the same boundaries as in the relation of body sway with the foreground. They looked at the image of the same virtual 3D scene on the screen, but neither of its planes was connected with the body sway.

According to the test program, the subjects were standing first on a firm and then on a compliant platform. The compliant platform was designed using a 10-cm-thick square plate of foam rubber, which was placed on the platform of stabilograph and covered by a 10-mm-thick plywood sheet; the sizes of the plates were identical to the sizes of the stabilograph platform. The pliancy of foam rubber reached nearly 3 cm at a pressure of 0.5 N/cm^2.

The subjects performed 28 tests during the experiment: 14 tests on the firm platform and 14 tests on the compliant platform. In total, four tests were performed with AR and four tests with CR between the VVE foreground and the body sway, as well as three tests in the MVE and three tests under the EC conditions. The recording time for a stabilogram was 40 s in the run. The interval between the tests lasted for nearly 1 min, and, after every four or five tests, the subjects took rest in a sitting position, not changing their plantar position. Visual conditions in each half of the experiment rotated at random.

The individual mean values for all tests were calculated from the derived data for each visual condition, and the group mean values were then calculated. One-way ANOVA was used to assess statistically the global

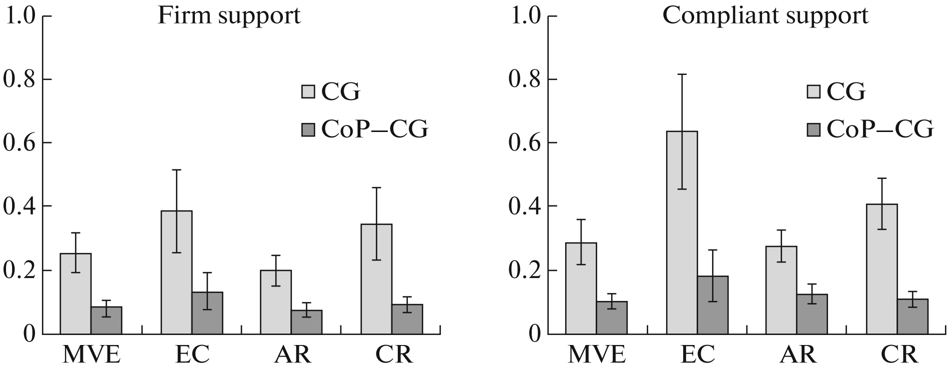

Fig. 1. Mean *RMS* values for the spectra of CG and CoP–CG variables and their standard errors calculated from the body sway in the motionless visual environment (MVE), eyes closed in a dark room (EC), antiphased relation (AR) and cophased relation (CR) of the VVE fluctuations with body sway. The ordinate axis shows the amplitude of sway in mm.

effect of the "visual control condition" and "support type" factors on the analyzed variables. The significance of differences between *RMS* and *MF* in the paired comparison of visual conditions was assessed by post-hoc analysis, using the paired two-sample *t* test for means.

RESULTS

Analysis of the RMS for the Spectra of the Variables Studied Estimated from the Plantar CoP Displacements in the Anteroposterior Direction

Figure 1 shows the overall *RMS* values for the amplitude spectra of the CG and CoP–CG variables calculated for all subjects from the results of the posture maintenance analysis for the firm and compliant supports. It is seen that the *RMS* for the spectra of both variables altered, due to changes in the visual conditions of posture maintenance. ANOVA has shown the statistically significant effect of the "visual control condition" factor on the spectrum *RMS* of the CG variable: Fisher's test for the firm support was $F_{3,\,52} = 10.26$, $p < 2.04E\text{-}05$; and for the compliant support $F_{3,\,52} = 33.07$, $p < 4.21E\text{–}12$. The amplitude spectra *RMS* of the CoP–CG variable was also visually dependent, although the effect of this factor was less expressed; ANOVA has detected the effect of this factor on the spectra *RMS* of the CoP–CG variable for both the firm ($F_{3,52} = 7.33$, $p < 0.00034$) and the compliant support ($F_{3,\,52} = 9.95$, $p < 2.73E\text{-}05$).

The post-hoc analysis has revealed the following assessments of differences between visual effects on posture maintenance.

Firm support. The *RMS* for the spectra of the CG variable was the least with AR, significantly differing from the values derived for the condition of posture maintenance in MVE ($t_{13} = -3.63$, $p < 0.002$), as well as for the CR ($t_{13} = -4.56$, $p < 0.0002$) and EC conditions ($t_{13} = -5.56$, $p < 0.000038$). The spectra *RMS* of the CG variable derived for the MVE condition significantly differed from the spectra *RMS* for the EC ($t_{13} = -4.42$, $p < 0.0003$) and CR conditions ($t_{13} = -3.49$, $p < 0.002$). No reliable differences between the *RMS* for the spectra of CG variable have been found by the statistical analysis when comparing the visual conditions with EC and CR.

The *RMS* for the spectra of the CoP–CG variable in different visual conditions changed not so significantly. Those were also the least in the AR condition, significantly differing from the values in the CR ($t_{13} = -2.67$, $p < 0.01$) and EC conditions ($t_{13} = -3.79$, $p < 0.0012$), and not differing from the values in the MVE condition ($p > 0.05$). *RMS* for the spectra of the CoP-CG variable obtained for the MVE and CR conditions significantly differed from the *RMS* for the spectra for the EC condition: $t_{13} = -4.13$, $p < 0.001$ in comparing the MVE and EC conditions; $t_{13} = -2.87$, $p < 0.007$ in comparing the CR and EC conditions. No reliable differences have been found between the *RMS* for the spectra of this variable obtained for the MVE and CR conditions ($p > 0.05$).

Compliant support. The assessment results on the differences between the visual effects on posture maintenance have proven to be somewhat different with this support.

In contrast with the firm support, a statistically significant difference has been found between the *RMS* for the spectra of the CG variable in the EC and CR conditions ($t_{13} = 4.35$, $p < 0.0004$). In addition, no differences have been found between the *RMS* for the spectra of the CG variable in the AR and MVE conditions ($p > 0.05$). The calculated *RMS* for the spectra of the CG variable in the AR conditions significantly differed from the values obtained for the CR ($t_{13} = -6.10$, $p < 0.00002$) and EC conditions ($t_{13} = -6.93$, $p < 0.000005$). The *RMS* for the spectra of the CG variable derived for the MVE condition significantly differed from the *RMS* of the spectra for EC ($t_{13} = -6.40$, $p <$

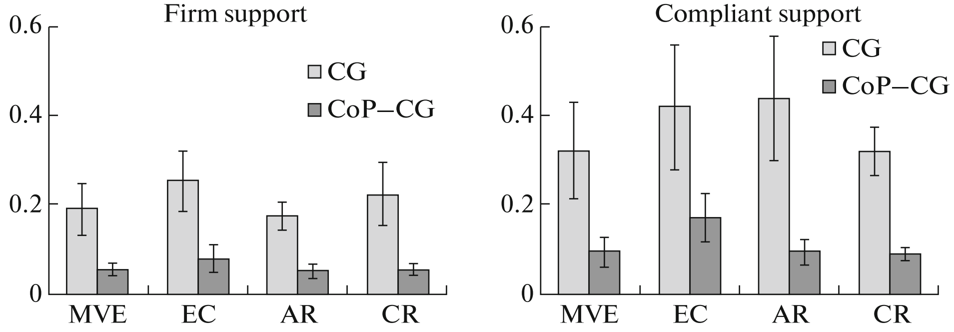

Fig. 2. Mean *RMS* values for the spectra of CG and CoP–CG variables and their standard errors calculated from the body in the lateral direction. See designations in Fig. 1.

0.00001) and CR conditions (t_{13} = –7.02, $p <$ 0.000005).

The *RMS* for the spectra of the CoP–CG variable had the least and similar values in the MVE and CR conditions, not differing significantly from the values derived for the AR (t_{13} = –2.82, $p < 0.007$ and t_{13} = –3.16, $p < 0.004$, respectively) and EC conditions (t_{13} = –3.92, $p < 0.0009$ and t_{13}= –3.61, $p < 0.002$, respectively). The *RMS* for the spectra of this variable was the highest for the EC condition and significantly exceeded the values for the AR condition (t_{13} = 3.09, $p < 0.004$).

The "type of support" factor also significantly affected the spectra of the CG and CoP–CG variables. The body sway was substantially greater in maintaining a vertical posture on the compliant support. ANOVA has revealed the global effect of this factor on the *RMS* of both variables: Fisher's test $F_{1,\,110}$ = 13.4, $p < 0.0004$ for the CG variable and $F_{1,\,110}$ = 16.1, $p < 0.0001$ for the CoP–CG variable.

The paired comparison of the *RMS* for the variables obtained in the same visual condition gave the following results. No statistically significant effects of the type of support factor on the *RMS* for the spectra of the CG variable have been found in standing in MVE conditions ($p > 0.05$). The *RMS* of this variable considerably increased in the remaining visual conditions after the passage to the posture maintenance on the compliant support: t_{13} = –3.57, $p < 0.002$ for the EC conditions, t_{13} = –5.02, $p < 0.0001$ for AR condition, and t_{13} = –2.12, $p < 0.03$ for the CR condition.

The *RMS* for the spectra of the CoP-CG variable calculated for all visual conditions, including MVE, were significantly lower if the subjects were standing on the firm support. The indicator for the significance of differences was t_{13} = –2.54, $p < 0.01$ for the MVE condition; t_{13} = –2.22, $p < 0.02$ for the EC condition; t_{13} = –6.55, $p < 0.00005$ for the AR condition; and t_{13} = –2.25, $p < 0.02$ for the CR condition.

Analysis of the RMS for the Spectra of the Variables Studied Calculated from the Plantar CoP Displacements in the Lateral Direction

Figure 2 shows the results of the analysis on the posture maintenance by subjects standing on the firm and compliant supports. As seen from the figure, the *RMS* for the spectra of both variables had lower values than those calculated from the fluctuations of the anteroposterior direction.

Firm support. The *RMS* spectra of both laterally directed variables depended on the visual conditions in a similar same way as did the *RMS* for the spectra of this variable of the anteroposterior direction. Those were the highest in the EC condition, the lowest in AR and MVE and close in the CR condition to the EC condition. ANOVA has shown a statistically significant effect of the "visual control condition" factor on the fluctuations of support-related responses in this direction: Fisher's test $F_{3,\,52}$ = 3.37, $p < 0.025$ for the CG variable; and $F_{3,\,52}$ = 4.82, $p < 0.005$ for the CoP – CG variable.

The assessment of the significance of differences between the visual effects on posture maintenance has revealed the following facts. The *RMS* for the spectra of the CG variable in the EC condition significantly differed from the values obtained for the MVE condition (t_{13} = 2.59, $p < 0.012$), as well as for the AR condition (t_{13} = 4.12, $p < 0.0005$). The *RMS* obtained for the AR condition were significantly less than the *RMS* values for CR (t_{13} = –2.081, $p < 0.03$).

In contrast to the CG variable, the *RMS* for the spectra of the CoP–CG variable obtained for the AR and CR conditions did not differ from one another. At the same time, the *RMS* for the spectra of this variable in the EC condition were also significantly greater than *RMS* under the MVE, AR and CR conditions (t_{13} = 4.05, $p < 0.001$; t_{13} = 3.01, $p < 0.005$; t_{13} = 2.19, $p < 0.03$, respectively).

Compliant support. ANOVA of the body sway during standing on the compliant support has shown a statistically significant effect of the "visual control condition" factor on the *RMS* for the spectra of the CG variable ($F_{3,\,52} = 4.05$, $p < 0.012$), as well as of the CoP–CG variable ($F_{3,\,52} = 7.56$, $p < 0.0003$).

The *RMS* for the spectra of both variables in the lateral direction in the posture maintenance on the compliant support changed somewhat differently due to the effect of visual conditions than in standing on the firm support. In particular, the *RMS* for the CG spectra was the highest under both EC and AR conditions, while the *RMS* of the CoP – CG variable derived for the AR and CR conditions did not differ from one another.

The post-hoc analysis gave the following results from the assessment of differences between the effects of visual conditions on the studied variables. The *RMS* for the spectra of the CG variable obtained in the AR and EC conditions did not differ from one another ($p > 0.05$). At the same time, the *RMS* for the spectra of this variable in the AR condition were significantly higher than the *RMS* for the spectra of this variable in the MVE and CR conditions ($t_{13} = 6.03$, $p < 0.00005$ and $t_{13} = 3.58$, $p < 0.002$, respectively). The *RMS* for the spectra of the CG variable in the EC condition were also significantly higher than the *RMS* of the spectra in the MVE and CR conditions ($t_{13} = 3.28$, $p < 0.003$ and $t_{13} = 2.38$, $p < 0.017$, respectively).

Paired comparison of the *RMS* values for the CoP–CG variable, which were calculated for the MVE, AR, and CR conditions, has not found any statistically significant differences between them. At the same time, the *RMS* of this variable in the EC condition significantly differed from the values derived in the remaining conditions. When the *RMS* for the spectra of CG variable were compared, the criterion was found to be $t_{13} = 3.39$, $p < 0.003$ in the MVE condition, $t_{13} = 3.42$, $p < 0.002$ in the AR condition, and $t_{13} = 3.63$, $p < 0.0015$ in the CR condition.

The "type of support" factor significantly affected the *RMS* for the spectra of the CG and CoP–CG variables. The body sway was significantly greater in the vertical posture maintenance on the compliant support. ANOVA has found the global effect of this factor on the *RMS* of both variables: Fisher's test for the CG variable was $F_{1,\,110} = 73.9$, $p < 6.21E{-}14$, while $F_{1,\,110} = 37.5$, $p < 1.41E{-}08$ for the CoP – CG variable.

Paired comparison of the spectra derived in the same visual conditions but with different (firm and compliant) supports gave the following results. Comparing the *RMS* for the spectra of the CG variable for the visual condition of MVE the criterion $t = -4.37$, $p < 0.0004$ for EC condition $t = -4.14$, $p < 0.0006$, $t = -8.09$, $p < 9.77E{-}07$ for AR condition, $t = -3.44$, $p < 0.0022$ for the CR condition.

The *RMS* for the spectra of the CoP – CG variable calculated for all compared pairs were also significantly less if subjects were standing on the firm support. The indicator for the significance of differences was $t = -4.36$, $p < 0.0004$ for the MVE condition; $t = -3.60$, $p < 0.002$ for the EC condition; $t = -4.77$, $p < 0.0002$ for AR; and $t = -6.76$, $p < 6.68E{-}06$ for the CR condition.

RESULTS AND DISCUSSION

Vision can play at least a double role in the stabilization of a human vertical posture. On the one hand, vision informs the CNS about the body sway relative to the outer environment, on the other hand, it assesses the degree of stationarity of the very environment. Therefore, it is important to understand how efficient the contribution of visual signals containing information about the body sway relative to the outer environment may be for the regulation of vertical posture under the conditions when its perception is destroyed (for example, in some vestibular disorders and other neurological diseases [29–32]). Our study has yielded important factual data that, as we believe, provide further insight into this problem.

We compared in our study the vertical posture maintenance in the motionless visual environment (MVE) combined with some conditions when the subject was "immersed" into a virtual nonstationary visual space. The destruction of the stationarity of the visual environment was induced by the adjustment (cophasally or antiphasally) of the VVE foreground position to the body sway.

The *RMS* for the spectra of the CG and CoP–CG variables calculated from the CoP fluctuations changed in a similar way as the visual conditions for posture maintenance changed. Those values decreased in the antiphased relation between the foreground and the body sway and decreased with the cophased relation, compared with the *RMS* derived in motionless visual environment (MVE). This result can be interpreted in the following way. The subjects during the posture maintenance, despite the instruction "to use a motionless background plane as a reference," unconsciously responded to the foreground fluctuations and corrected the posture in correspondence with the direction of these fluctuations. In the case of antiphased relation, this led to the situation when corrective forces caused antiphased foreground displacements corresponding to a subject's habitual structure of motion parallax, when the objects located closer than the point of fixation move in the direction opposite to the observer's motion. As a result, this led even to a small decrease in the postural sway. On the contrary, corrective forces in the cophased relation were accompanied by the emergence of unusual inverted form of motion parallax, as a result of which the foreground was perceived as moving in the same direction with a subject's movements. This very circumstance seemed to be the cause of additional postural destabilization. At the same time, it should be noted that the maximum body sway in the CR effect condition did not exceed the values characteristic of the stance with EC. This circumstance indicates that the subjects succeeded, to a considerable degree, to overcome the effect of visual signals destabilizing the posture and related to the foreground sway.

The sway of the body CG in maintaining the vertical posture on the compliant support significantly increased under all visual conditions. However, in contrast to what was observed on the firm support, these sways were significantly smaller under the CR condition than in the posture maintenance with EC (Figs. 1, 2). It was initially suggested that the cophased relation combined with the compliant support will result in the highest increase in body sway, but this did not occur. We can suggest that some postural stabilization in this condition was related to partially ignored signals from visual organs and the increase in the contribution of information on the body stance to the posture maintenance from nonvisual sensor sources (muscular, articular, and vestibular).

The *RMS* for the spectra of CoP–CG variable did not change in direct proportion to changes in the *RMS* for the spectra of the CG variable after the passage to the stance on the compliant support in the visual AR and CR conditions. For example, the *RMS* for the spectra of the CoP–CG variable for the AR condition (anteroposterior direction) was higher than for the CR condition, whereas the *RMS* for the spectra of the CG variable, on the contrary, were considerably less for the AR condition than for the CR condition. Thus, reflecting the process of vertical posture maintenance, the amplitude characteristics of elementary variables (CG and CoP–CG) could change due to changes in visual conditions not only nonproportionately, but also even multidirectionally. Since the CoP–CG variable is the indicator of changes in the resultant musculo-articular stiffness, we can suggest that the formation of the latter was not the same as with the firm support. This result was quite unexpected and, therefore, is not simple for interpretation. Some reasons for its understanding are given by some current studies related to the two-component nature of musculo-articular stiffness [33–35]. These studies distinguish two components: the active muscular contractile component and the passive elastic fascial tendinous component. It has especially been shown that their relative contribution to the formation of resultant stiffness in different conditions may vary by gender groups. For example, the passive elastic component made a larger contribution to the resultant stiffness in male subjects, while the active muscular component is more expressed in female subjects [35].

CONCLUSIONS

Thus, based on our results, we can suggest that the identified nonproportionality in the changes of two variables under the conditions of compliant platform could reflect the participation of another variable value in the formation of the resultant musculo-articular stiffness, namely, its passive elastic component formed by fascial tendinous tissues. However, this suggestion requires additional experimental research.

The results obtained in this study, to a certain degree, contradict the hypothesis [17, 19] that changes in the value of body sway due to different visual conditions can be explained quite simply, proceeding from changes in the resultant musculo-articular stiffness automatically adjusted based on the effects coming from different neural structures of postural regulation.

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