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Computerized Stabilometry on a Four-Legged Platform for Comparative Analysis of Foot Positioning

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Computerized stabilometry using a four-legged stabilometric platform allows "free" positioning of the feet to be used, which is of fundamental importance for patients and subjects of different ages. The design of the stabilometric platform is important for finding the optimal positioning of the feet in controlling upright standing, treatment, and interpretation of results and comparison with other studies.

Introduction

Computerized stabilometry (CSM) is a basic approach to studying the operation of the brain used in posturology. CSM involves assessing the balance function in a standing person. It is based on recording the trajectory of displacement of the center of pressure in the plane of the support in the standing position at rest and on a great diversity of diagnostic tests [1]. The use of instruments from different makers introduces methodological errors in relation to sex, age, illness, psychoemotional state, and platform design [1-5].

Positioning of the person's feet on the stabilometric platform is important for correct use of CSM. The following are recognized: the "European" posture (feet diverging at an angle of 30° and a distance of 2 cm between the medial surfaces of the heels) and the normalized "American" posture (feet parallel to each other at a distance determined by the subject's anthropometric measure, i.e., the distance between the anterior superior iliac spines) [6]. There is also a "free" stance, which visually is an intermediate position between the "European" and "American" postures. Selection of posture variants depends on stereotypes, countries, and technical aspects of the apparatus used [6, 7]. In the "free" stance the muscles involved in maintaining the vertical posture in healthy and, especially, sick people have the normal tone.

The state of the problem and the demand for a state-of-the-art stabilometric platform have been described in [1, 2, 6, 7]. Most models of Russian and foreign stabilometric platforms use a three-legged arrangement, which significantly reduces the number of technical problems. However, this scheme has some drawbacks associated with the narrow range of coordinates of the center of pressure (CP), the minimal radius of the recording field, and the lack of opportunity to determine stabilometric parameters of the "free" positioning of the feet. Using four-legged platforms of the same size, the recording field radius is twice as large and the area around three times bigger [8].

The aim of this work was to run a comparative analysis of stabilometric parameters for the "American," "European," and "free" foot positionings on a four-legged version of the stabilometric platform.

Materials and Methods

Studies were carried out at the Laboratory of Physical Methods for Diagnosis and Treatment, Rostov State Medical University. CSM was carried out in healthy male student volunteers ($n = 74$), aged 19.7 ± 0.2 years; height, 176.9 ± 0.6 cm; weight, 71.5 ± 0.8 kg; BMI, 22.8 ± 0.9 kg/m^2.

Studies used a Stabilan-01-2 stabilometric analyzer with biological feedback (ZAO OKB Ritm, Taganrog) in the full professional version for medical-biological research. A tolerance control (TC) method was used following the manufacturer's recommendations [8].

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In this apparatus, the range of coordinates of the center of pressure (CP) is ±200 mm from the center of the stabilometric platform due to the use of the four-legged version and "centering" operations (coincidence of the mathematically expected position of the CP and the center of the coordinate axes over the whole of the recording field). Sampling frequency for the stabilographic signal was 50 Hz; resolution, 0.01 mm. The range of subject's weight and the ballistogram was 0-150 kg with a resolution of 1 g. Error levels in determination of CP coordinates were in the range 0.3-0.5%. The dimensions of the platform were 500 × 500 × 65 mm; its weight, including built-in electronics, was about 10 kg. The resonance frequency of the rigid stabilometric platform was 500 Hz without the detachable mass and 30 Hz the largest mass attached to it [1, 8].

The TC method involves three trials: with the eyes open (baseline), the Romberg test, and the "Target" test. The baseline test used visual stimulation in the form of alternating circles of different colors and counting of the number of white circles. The eyes-closed test used sound stimuli consisting of tonal signals that had to be counted, allowing switching of attention. In the "Target" test, the subject had to maintain a marker at the center of a target on a large-scale display. Instructions were given and subjects performed a test trial. Studies were carried out using the recommended workplace arrangement, without shoes and in the following order: "free," "American," and "European" foot positionings [8, 9]. Positions corresponded to recommendations [2] in relation to reference points and lines. The main indicators in the TC methods for comparison of results were taken from [10]. Stabilometric indicators reported in [3, 4] were studied.

Data were processed using Statistica 12.0 (Statsoft, USA). Normal distributions were identified using the Kolmogorov–Smirnov test. Mean values for independent sets were compared (between three or more groups) using analysis of variance with the Kruskal–Wallis test. Between-group pairwise comparisons as a step in analysis of variance used the Mann–Whitney test. Mean values from different trial results (eyes open, eyes closed) were compared using the Wilcoxon test for dependent sets. Differences were regarded as statistically significant at a significance level of 95% ($p \leq 0.05$).

Results and Discussion

The area of the statokinesiogram ellipse characterizes the support area (*EllS,* mm^2), which in healthy humans ranges from 30 to 400 mm^2 [10]. Comparison of the results showed that the support area was significantly smaller in the "American" stance (52.2 ± 4.4 mm^2) and largest in the "European" stance (136.1 ± 20.1 mm^2) (Table 1).

The Romberg test induced a significant increase in *EllS* in all groups of subjects. However, this increase was the smallest (36.8%) in the "free" stance, where calculation of *KoefRomb* showed the smallest value (172.2%), significantly less than in the "European" stance. In the "European" stance, *KoefRomb* approached 250% (when visual control was needed for standing upright) [10].

Assessment of the length of the statokinesiogram with the eyes open (*LFSo*) showed the smallest value in the "European" stance, though the value did not differ with statistical significance from the value in the "free" stance (1.85 and 2.05 1/mm, respectively). In the "American" stance, despite the smallest *EllSo*, *LFSo* was the longest.

Exclusion of visual control decreased *LFSc*, this being statistically significant only in the "European" stance, where the decrease was by 30.3%. Data reported by Gagey and Weber (2008) indicated that the correlation between path length and area was low. The probable explanation of the increase in *EllSc* with decreasing *LFS* (especially with the eyes closed — *LFSc*) is unconscious immobilization of the subject.

The balance function coefficient (BFC, %) was introduced to exclude significant individual data spread in *EllS* and *LFS* [11]. BFC is an integral vector analysis indicator reflecting the coefficient of changes to the linear speed function. The greater the value, the better the body's balance system is functioning. The "European" stance with the eyes open gave the lowest value (81.4%) as compared with other stances, between which there was no statistically significant difference. The Romberg test decreased BFC in all groups. Values for BFC were essentially identical in the "free" and "American" stances (79.1% and 80.0%, respectively), while BFCc in the "European" stance reached 66.2%, which was 15.2% lower than with visual control. The "Target" test is a static motor-cognitive test with biological feedback. It provides assessment of the state of attention and the concordance of visual perception and muscle control [9]. In the "European" positioning of the feet, BFC*t* was also significantly lower than in the "free" or "American" stances. Further assessments of stabilometric indicators were obtained (Table 2).

The stability of volunteers was assessed in terms of the following measures: *R* — mean spread (radius) of deviations in the CP (mm) and the corresponding directions relative to the displacement of the CP — $Q(x)$ and $Q(y)$ — in the frontal and sagittal planes, respectively. Increases in *R* indicate decreased stability in all planes. Table 2 shows that the *R* value was lowest (2.59 mm) with

TABLE 1. Comparison of Main Stabilometric Indicators Depending on Foot Positioning ($M \pm m$)

Parameters	"Free" (1)	"American" (2)	"European" (3)	p
1. *EllS*o, mm^2, eyes open	88.7 ± 8.7	52.2 ± 4.4	136.1 ± 20.1	$p_{\text{mult}} = 0.018$; $p_{2\text{-}1} = 0.0003$; $p_{3\text{-}1} = 0.034$; $p_{3\text{-}2} < 0.001$
2. *EllS*c, mm^2, eyes closed	121.3 ± 9.7 between (1) and (2) + 36.8 %, $p^* = 0.014$	92.4 ± 14.3 between (1) and (2) + 77.0 %, $p^* = 0.009$	261.7 ± 22.0 between (1) and (2) + 92.3 %, $p^* < 0.001$	$p_{\text{mult}} = 0.04$; $p_{2\text{-}1} > 0.05$; $p_{3\text{-}1} < 0.001$; $p_{3\text{-}2} < 0.001$
3. *KoefRomb*, %	177.2 ± 12.6	200.4 ± 14.8	241.4 ± 14.1	$p_{\text{mult}} = 0.021$; $p_{2\text{-}1} > 0.05$; $p_{3\text{-}1} = 0.001$; $p_{3\text{-}2} = 0.048$
4. *LFS*o, 1/mm	2.05 ± 0.14	3.23 ± 0.20	1.85 ± 0.10	$p_{\text{mult}} = 0.003$; $p_{2\text{-}1} < 0.001$; $p_{3\text{-}1} > 0.05$; $p_{3\text{-}2} < 0.001$
5. *LFS*c, 1/mm	1.87 ± 0.11 between (4) and (5), – 8.8 %	2.69 ± 0.20 between (4) and (5), – 16.7 %	1.29 ± 0.08 between (4) and (5), – 30.3 %. $p^* < 0.001$	$p_{\text{mult}} < 0.001$; $p_{2\text{-}1} < 0.001$; $p_{3\text{-}1} < 0.001$; $p_{3\text{-}2} < 0.001$
6. BFCo, %, eyes open	88.5 ± 0.8	86.5 ± 1.2	81.4 ± 1.2	$p_{\text{mult}} < 0.001$; $p_{2\text{-}1} > 0.05$; $p_{3\text{-}1} < 0.001$; $p_{3\text{-}2} = 0.003$
7. BFCc, %, eyes closed	79.1 ± 1.4 between (6) and (7), $p^* < 0.001$	80.0 ± 1.4 between (6) and (7), $p^* < 0.001$	66.2 ± 1.8 between (6) and (7), $p^* < 0.001$	$p_{\text{mult}} < 0.001$; $p_{2\text{-}1} > 0.05$; $p_{3\text{-}1} < 0.001$; $p_{3\text{-}2} < 0.001$
8. BFC*t*, %, "Target" trial	76.5 ± 1.8	81.7 ± 1.2	71.7 ± 1.6	$p_{\text{mult}} = 0.03$; $p_{2\text{-}1} > 0.05$; $p_{3\text{-}1} = 0.05$; $p_{3\text{-}2} < 0.001$

the eyes open in the "American" stance, followed by the "free" positioning (3.24 mm), while the "worst" values were seen with the "European" stance (3.84 mm). The Romberg test showed a significant increase in R (reduced stability), with a smaller increase in the "free" stance and larger increases in the "American" and "European" stances (by 33.2% and 39.8%, respectively).

Considering foot positioning in the "American" stance, we would expect significant stability in the frontal plane $Q(x)$, which was 1.37 mm. Subjects were 1.5 times less stable in the "free" stance in the frontal and 2.3 times less stable in "European" stance. The Romberg test led to a decrease in stability in this plane. It decreased significantly only in the "European" stance (+26.8% increase in value). In the "American" stance, the decrease in stability compared with the eyes open was also greater (+13.1%) than in the "free" stance (+9.2%).

Using assessment of stability in the sagittal plane $Q(y)$ as an example, the importance of visual control for standing upright was particularly notable. With the eyes open, values were virtually identical in all stances. However, the Romberg test led to a significant degradation of stability of all stances in the following order: "free," "American," and "European" (by 26.9%, 41.4%, and 54.6%, respectively).

The coefficient of abrupt change in movement direction (CACMD) was recorded when the angle between two neighboring vectors was greater than 45° and reflected sharp turns in the rate vector relative to the total quantity of vectors and specific brain activities in correcting the standing

TABLE 2. Comparison of Stabilometric Indicators Depending on Foot Positioning ($M \pm m$)

Parameters	"Free" (1)	"American" (2)	"European" (3)	p
1. Ro, mm, eyes open	3.24 ± 0.16	2.59 ± 0.11	3.84 ± 0.21	$p_{\text{mult}} = 0.002$ $p_{2\text{-}1} = 0.001$ $p_{3\text{-}1} = 0.025$ $p_{3\text{-}2} < 0.001$
2. Rc, mm, eyes closed	3.86 ± 0.15 between (1) and (2), + 19.1 % $p^* = 0.014$	3.45 ± 0.25 between (1) and (2), + 33.2 % $p^* = 0.014$	5.37 ± 0.22 between (1) and (2), + 39.8 % $p^* = 0.014$	$p_{\text{mult}} = 0.004$ $p_{2\text{-}1} > 0.05$ $p_{3\text{-}1} < 0.001$ $p_{3\text{-}2} < 0.001$
3. Q(x)o, mm, eyes open	2.06 ± 0.15	1.37 ± 0.07	3.17 ± 0.12	$p_{\text{mult}} < 0.001$ $p_{2\text{-}1} < 0.001$ $p_{3\text{-}1} < 0.001$ $p_{3\text{-}2} < 0.001$
4. Q(x)c, mm, eyes closed	2.25 ± 0.12 between (3) and (4), + 9.2 %	1.55 ± 0.10 between (3) and (4), + 13.1 %	4.02 ± 0.19 between (3) and (4), + 26.8 %. $p^* < 0.001$	$p_{\text{mult}} < 0.001$ $p_{2\text{-}1} < 0.001$ $p_{3\text{-}1} < 0.001$ $p_{3\text{-}2} < 0.001$
5. Q(y)o, mm, eyes open	2.97 ± 0.16	2.63 ± 0.12	2.93 ± 0.26	$p_{\text{mult}} > 0.05$ $p_{2\text{-}1} > 0.05$ $p_{3\text{-}1} > 0.05$ $p_{3\text{-}2} > 0.05$
6. Q(y)c, mm, eyes closed	3.77 ± 0.15 between (5) and (6), + 26.9 %. $p^* < 0.001$	3.72 ± 0.27 between (5) and (6), + 41.4 %. $p^* < 0.001$	4.53 ± 0.21 between (5) and (6), + 54.6 %. $p^* < 0.001$	$p_{\text{mult}} = 0.01$ $p_{2\text{-}1} > 0.05$ $p_{3\text{-}1} = 0.004$ $p_{3\text{-}2} = 0.019$
7. CACMDo, %, eyes open	16.18 ± 0.81	18.36 ± 0.81	14.36 ± 0.81	$p_{\text{mult}} = 0.042$ $p_{2\text{-}1} > 0.05$ $p_{3\text{-}1} > 0.05$ $p_{3\text{-}2} < 0.001$
8. CACMDc, %, eyes closed	13.60 ± 0.62 between (7) and (8), $p^* = 0.01$	15.94 ± 0.72 between (7) and (8), $p^* = 0.029$	11.75 ± 0.68 between (7) and (8), $p^* = 0.015$	$p_{\text{mult}} = 0.037$ $p_{2\text{-}1} = 0.016$ $p_{3\text{-}1} > 0.05$ $p_{3\text{-}2} < 0.001$

posture. CACMD with the eyes open in the "European" positioning of the feet had the lowest value, probably due to the short length of the statokinesiogram. At the same time, in the "American" stance, with the longest *LFD* and smallest area of the ellipse, the value of this parameter was greatest (18.36%). The Romberg test led to further decreases in this parameter in all stances, especially the "European," which is evidence for conscious–unconscious immobilization of the subject to prevent possible falls.

Conclusions

The widely recommended "European" positioning of the feet [2, 6, 9] gave the largest support area as compared with the "free" and "American" stances. In the "European" stance, reorientation of the balance control system in the Romberg test to proprioception significantly decreased drift of the CP in subjects within the area of the ellipse. These data indicate that the "European" stance for a healthy young person is immobilizing in terms of movement of the CP, which is also indicated by values of CACMD, when, with maximal *EllS* and minimal *LFS* in this stance, conscious–unconscious immobilization of the subject had an effect aimed at preventing possible falls. All this leads to the lowest level of stability of the subject in all planes. Rejecting a strategy of maintaining balance, this stance puts the lower limb joints into a more complex mutual positioning, and control of balance in the frontal plane is mediated by the subtalar joints [2, 6, 9]. BFC was also significantly lower in the "European" stance with the eyes both open and closed and in the trial with concordance between visual perception and muscle control. However, in our view, this allows this foot positioning to be recommended for use in biological feedback trainers, improving measures in patients with different degrees of freedom in CP displacement.

Greater stability of subjects in the frontal plane with the feet positioned parallel to each other at different distances from each other (widening of the support base) was demonstrated in a previous study [12]. This positioning is especially efficient if there is a risk of impaired balance in this plane (ships, vehicles, etc.).

The stance most preferred for control of upright standing is the "free" stance. This is probably associated with the equal distances of the CP from any of the edges of the support surface and the correct muscle tone involved in maintaining the vertical posture [2, 9]. This foot positioning will be more appropriate for individualization of treatment dynamics and determining the effectiveness of pharmacotherapy and physical rehabilitation methods.

This study did not aim to juxtapose one stance against another or seek the "best." Studying different foot positionings on the four-legged stabilometric platform allows detecting significant differences in the control of the upright posture with visual control in different categories of people. This is important for interpretation of the results obtained here, comparing them with those of other studies and selecting normal or pathological states for investigation.

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