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THE COMPARISON OF EFFECTS OF SHANK MUSCLES VIBRATION DURING STANDING ON ONE AND TWO LEGS

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Abstract: We studied the influence of vibratory stimulation of shank muscles proprioceptors on equilibrium maintenance in postures with different stability. 12 practically healthy subjects participated in the study. Subject stood on a stabilograph with eyes opened on two or one leg. When subject stood on one leg the other (not weight bearing) leg was freely hanging. The tendon of triceps surae or tibialis anterior muscle of one leg was subjected to moderate vibration. Vibration was always applied to weight-supporting leg. Body tilt evoked by vibratory stimulation was less pronounced during standing on one leg than during usual standing. The relative increase of stabiligram lengths during vibration when standing on one leg was also less than in bipedal standing. So the influence of the proprioceptive system disturbance decreases with increase of posture instability. Apparently, when standing on one leg the central nervous system preferably uses visual and vestibular information and also information from muscles-antagonists.

Key words: orthograde posture**,** equilibrium mainetenance, posture with different stability, vibration, proprioception

Introduction

It was shown elsewhere [1] that vibratory activation of receptors of muscles, which took part in equilibrium maintenance in the frontal plane, produced most prominent effects on posture maintenance in a stable body position (with increased support, with subject's feet apart) and was practically non-effective in unstable posture (feet in tandem). Thus in this respect proprioceptive perturbations differ strongly from visual and vestibular perturbations, as their influence becomes more prominent with increase of posture stability [2, 3].

In present work we continued the study of the influence of vibratory stimulation of shank muscles proprioceptors on equilibrium maintenance in postures with different stabilities. The usual standing and standing on one leg were chosen as postures with different stabilities. Preliminary results of this work were reported elsewhere [4, 5].

Materials and methods

Twelve apparently healthy subjects (aged from 21 to 52 years) without any known neurological or motor disorders participated in the study. During the experiment the subjects stood with eyes opened on two or one leg. Subject's feet were positioned on wooden pedestals 10 cm x 18 cm x 40 cm (H x W x L) placed on a stabilograph (force platform). The pedestals were narrower and shorter (10x8x30 cm) in preliminary experiments [4]. When subject stood on one leg the other (not weight bearing) leg was freely hanging since one of the pedestals was taken away. The tendon of triceps surae (TS) muscle (experiment 1: 12 subjects) or tendon of tibialis anterior (TA) muscle (experiment 2: 11 subjects) of one leg was subjected to moderate vibration (30 Hz, 0.8 mm peak-to-peak amplitude, which did not depend on the pressure applied to vibrator). When the subjects stood on one leg, this weight-supporting leg was vibrated.

The vibration was applied by electromechanical vibrator (DC-motor DPM-30-N1-01, Voronezh, Russia, equipped with eccentrics) fixed over the TS or TA tendon with elastic band. The same vibrator was used for the right and left leg vibrations.

The signals of the force platform were amplified, digitized with the sampling rate 20 s^{-1} and stored in the computer. Prior to the analysis the data were filtered by a low-pass filter of forth order with a cut-off frequency of 2 Hz. The lengths of the frontal and sagittal stabilograms and changes of the center of gravity position (CGP) were used for result analysis.

In each experiment there were 4 types of trials:

1) subject stood on two legs, tendon on the right leg was vibrated (will be designated below as 2, d);

2) subject stood on two legs, tendon on the left leg was vibrated (2, s);

3) subject stood on the right leg, tendon on the right leg was vibrated (1, d);

4) subject stood on the left leg, tendon on the left leg was vibrated (1, s).

For each type 4 records were made. The record duration was 60 seconds, vibration was applied from 20th to 40th second. The following order of trial conditions was used: at first vibration was applied to the tendon on the right leg and trials (2,d), (2,d), (1,d), (1,d), (2,d), (2,d), (1,d), (1,d) were made, then the tendon on the left leg was vibrated, and trials were conducted in the same sequence. Between tests subjects rested sitting in a chair for 2-3 minutes. The feet position of the subject was plotted on the paper attached to the pedestal at the beginning of the experiment, so after the rest the subject put feet on the same place.

Results and discussion

In preliminary experiments at 9 subjects it was shown [4] that during standing on one leg CGP shifted under the influence of TS tendon vibration on the average 3-3.5 times less (0.8 cm) than during standing on both legs. The length of frontal stabilogram during vibration was nearly the same as the length before vibration. During one leg standing vibration the length of sagittal stabilogram increased on the average only by 26-28% though during usual standing length increased by 200%. Since pedestals used in [4] were narrow and some subjects experienced difficulties during standing on one leg, we undertook the present investigation with larger pedestals. In addition we studied the influence of TA tendon vibration.

The examples of stabilographic curves for all experimental conditions, i.e. when standing on one or two legs, with the right or left TS or TA tendon vibration, are shown in Fig. 1.

First of all it should be noted that moderate tendon vibration of one leg of the subject standing on both legs gave rise to the same body deviation as vibration applied to both legs, despite of undistorted proprioceptive afferentation coming from the other leg (Fig.1 a, b, e, F). During TS vibration the CGP shifted backward on the average by 3.2 cm (in the experiment 1) and forward during TA vibration on the average by 4.6 cm (the right TA vibration) or 3.7 cm (the left TA vibration) (in the experiment 2).

When the subjects stood on one leg (right or left) the vibration of its TS or TA tendon did not cause tilt of the body (Fig. 1c, d, h, g).

2D-CGP trajectories in the experiments with vibration of TS tendon of the right (A) and left (B) legs and TA tendon of the right (C) and left (D) legs when standing on both and one leg for curves represented in Fig. 1 are shown in Fig. 2. Elongated trajectories correspond to the usual standing because during vibration CGP shifted backward (Fig. 2 a, b) or forward (Fig. 2 c, d) and after the end of vibration returned to initial position. During standing on one

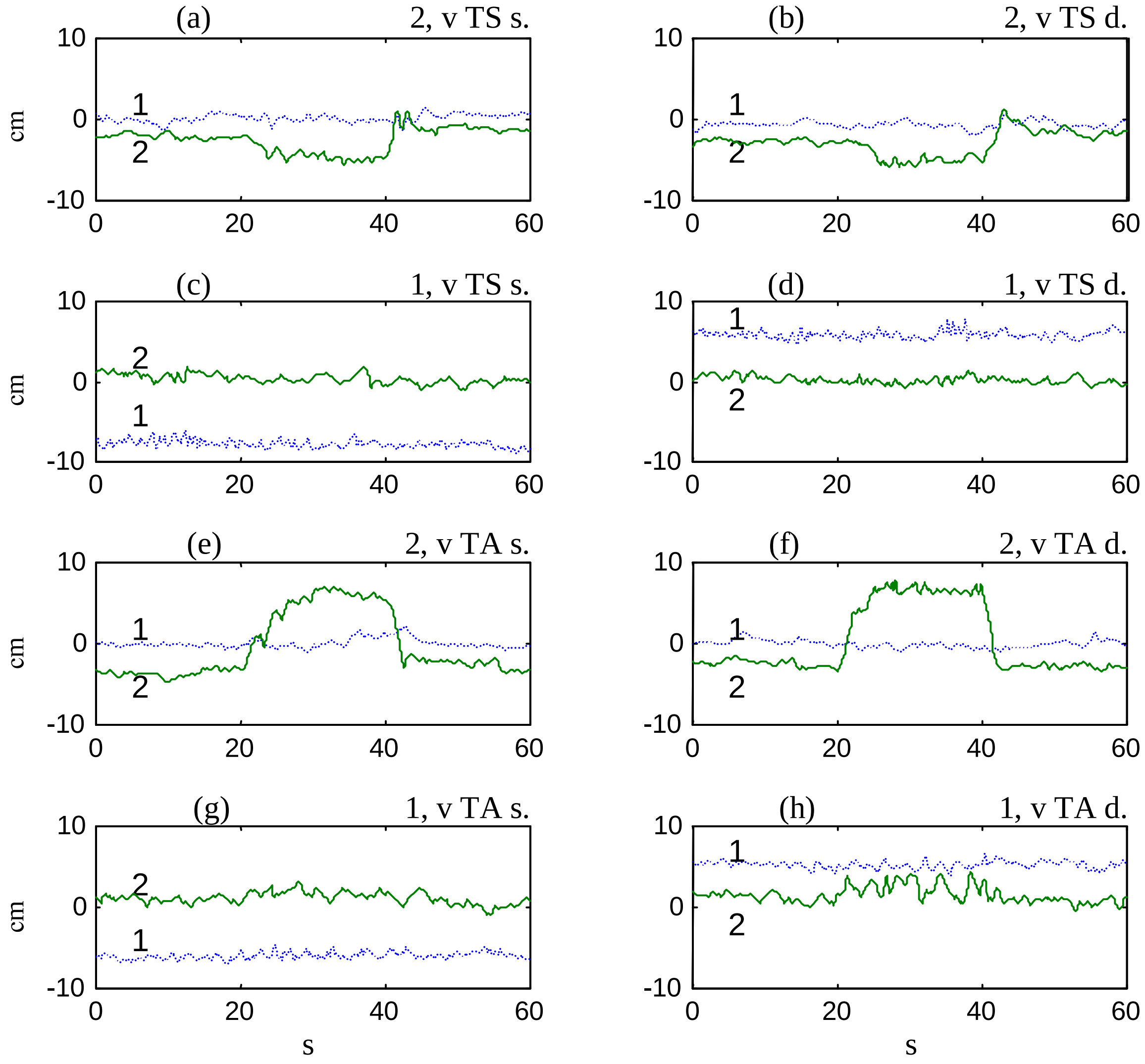

Fig.1. The effect of vibration (from 20 to 40 s) on stabilogram in frontal (curve 1) and in sagittal (curve 2) planes during usual standing (2) and standing on one leg (1). Conventional signs: v TS s.(d.) – vibration of TS tendon on the left (right) leg, v TA s. (d.) – TA tendon of the left (right) leg vibration. The curve deviation upwards corresponds to CGP shift to the right for frontal and forward for sagittal stabilograms.

leg without vibration, CGP of this subject shifted to the right or to the left and a little forward in comparison with standing on both legs; during vibration further forward or backward tilt did not occur.

After transition from standing on both legs to standing on the right or left leg, CGP of all subjects shifted respectively to the right (by 7.5-7.8 cm) or to the left (by 7.1-7.3 cm) and forward (to 5.5 cm) or backward (to 3.5 cm). The forward shift was more frequent, so the average shift value was 0.6-1.5 cm. The length of the curve increased 2.5-3 times in frontal plane and 2.2-2.7 times in sagittal plane .

During standing on one leg the CGP shift under the influence of TS tendon vibration was smaller than during standing on both legs in half of the cases. The CGP shift during standing on one leg was larger than during standing on both legs for one subject while standing on the right leg and for two subjects while standing on the left leg. In other cases differences were negligible. During standing on the right leg the CGP shift under the influence of TA tendon vibration was smaller than during standing on two legs in 5 cases from 11 and larger in 4 cases. During standing on the left leg these values made up 4 and 4.

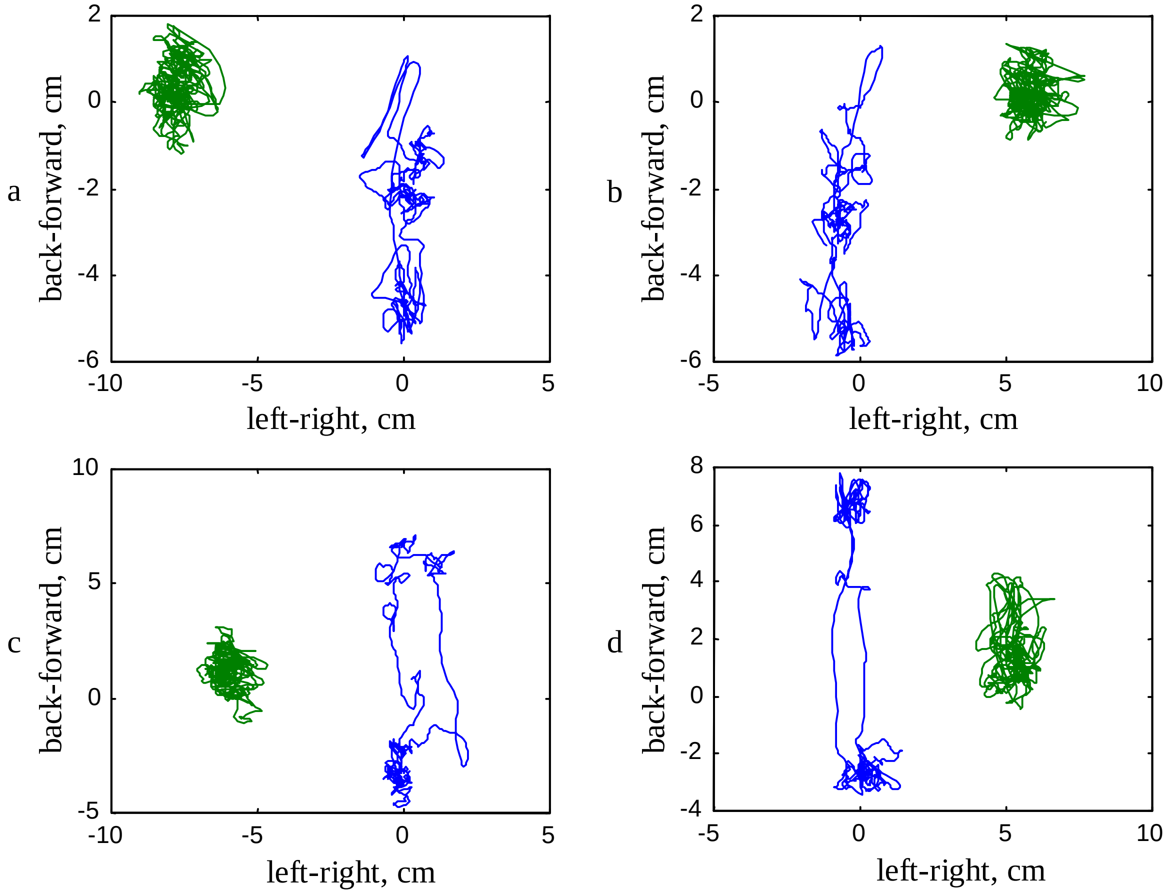

Fig.2. CGP trajectories in the experiments with TS tendon of the left (a) and right (b) legs and TA tendon of the left (c) and right (d) legs vibration (according to data given in Fig. 1).

Table 1. CGP shift (cm) in sagittal plane under the influence of vibration during usual standing (2) and standing on one leg (1).

Subjects	**TS tendon vibration**		**TA tendon vibration**	
	2	1	2	1
T.K.	-1.81 ± 0.39	-0.73 ± 0.27	7.86 ± 1.11	0.89 ± 0.32
Yu.L.	-3.00 ± 0.86	-0.91 ± 2.01	9.28 ± 1.65	2.16 ± 1.26
I.S.	-3.39 ± 0.54	0.66 ± 0.47	4.76 ± 1.22	1.72 ± 0.51
V.Sh.	-2.90 ± 0.66	-1.05 ± 0.75	3.20 ± 1.32	0.72 ± 0.56
Yu.I.	-6.51 ± 0.82	-4.68 ± 0.55	3.28 ± 0.88	5.34 ± 0.82
O.K.	-4.34 ± 0.63	-3.90 ± 0.91	2.96 ± 0.67	3.72 ± 1.23
V.K.	-3.88 ± 1.03	-2.74 ± 1.28	0.93 ± 0.74	1.79 ± 0.61
K.P.	-2.43 ± 0.71	-4.01 ± 0.36	4.20 ± 1.61	3.25 ± 0.86
A.B.	-3.74 ± 1.55	-4.17 ± 0.41	3.77 ± 1.00	6.24 ± 1.28
I.L.	-1.97 ± 0.49	-2.20 ± 0.69	3.15 ± 0.43	3.14 ± 0.56
V.T.	-2.61 ± 0.44	-2.25 ± 0.69	2.02 ± 1.00	1.95 ± 0.56
N.D.	-2.01 ± 0.72	-0.03 ± 0.83		
Mean ± std	**-3.22±1.31**	**-2.28±1.61**	**4.13±2.44**	**2.81±1.7**

Table 2. The lengths of frontal (F) and sagittal (S) stabilograms (cm) on the average for all subjects.

Type of trial	**F**	**S**
usual standing, before vibration	37	34
usual standing, during vibration	58	68
standing on one leg, before vibration	104	82
standing on one leg, during vibration	126	115

Table 1 shows values of CGP shift in sagittal plane under the influence of vibration during usual standing and standing on one leg. The data for the right and left legs were combined into one group. In 7 subjects CGP shift during TS tendon vibration when standing on one leg was smaller in comparison with usual standing. One subject had CGP shift greater than during usual standing and for the others differences were negligible. During TA tendon vibration when standing on one leg 4 subjects had smaller CGP shift as compared with usual standing, 3 subjects had greater shift and in the other cases differences were negligible. On the average for all subjects when standing on one leg CGP shift under the action of TS tendon vibration was 1.41 times less (difference is plausible) than during usual standing; and when TA tendon was vibrated it was 1.47 times less (difference is not plausible). Thus TS tendon vibration was less effective than TA tendon vibration.

When the subjects stood on both legs the length of the curve in the frontal plane during vibration increased 1.7 times in the experiment 1 and 1.5 times in the experiment 2, and in the sagittal plane did by a factor of 2 in both experiments (average values for all subjects).

When during TS tendon vibration the subjects stood on one leg the length of frontal stabilogram increased in comparison with initial value before vibration by factors 1.3 and 1.4 (for the right and left legs) and the length of sagittal stabilogram did by factors 1.4 and 1.7. During TA tendon vibration the length of frontal stabilogram practically did not change and the length of sagittal one increased by factors 1.3 and 1.4.

Results listed above show that the postural reaction on TS and TA tendon vibration differed by the direction of CGP shift; however the differences in lengths were similar. So, for length analysis the data, received during TS and TA tendon vibration of the right and left legs, were combined in one group.

The lengths of frontal and sagittal stabilograms while standing on both legs and one leg before vibration (in cm) and after vibration (in % to the curve length for the same period of time before vibration) are shown in Fig. 3. When subjects stood on both legs the frontal stabilogram length was 37 ± 10.2 cm and sagittal stabilogram length was 34 ± 9.5 cm (averaged values for all subjects). When subjects stood on one leg the length of frontal stabilogram increased on the average 2.8 times (from 1.6 to 3.5 for different subjects). The length of sagittal stabilogram increased on the average 2.4 times (from 1.7 to 3.3). During vibration the curves lengths increased more when subjects stood on two legs (mean values for all subjects were 158% (frontal) and 200% (sagittal)) than when subjects stood on one leg (mean values were 121% (frontal) and 141% (sagittal)). The differences were significant for all subjects except two subjects for frontal stabilogram and three subjects for sagittal stabilogram.

Mean values of curves lengths in frontal and sagittal planes over all subjects during vibration under the conditions of usual standing and standing on one leg are listed in Table 2. Comparative increase of stabilogram lengths in the period of vibration with respect to initial condition (before vibration) during usual standing was more (158 % in frontal plane and 200 % in sagittal plane) than during standing on one leg (121 % in frontal plane and 141 % in sagittal plane). Nevertheless absolute values show that the increase of curve lengths due to vibration during standing and standing on one leg was equal (21-22 cm in frontal plane and 33-34 cm in sagittal plane).

Present study demonstrated that CGP shift due to vibratory stimulation was less pronounced during standing on one leg than during usual standing, although not in all subjects. Even though the absolute enhancement of the lengths of curves elicited by vibration during standing on one leg (on the average over all subjects) were the same as during usual standing (Table 2), the relative increase of curve lengths during vibration in one leg standing was less almost for all subjects. So it may be assumed that the influence of the proprioceptive

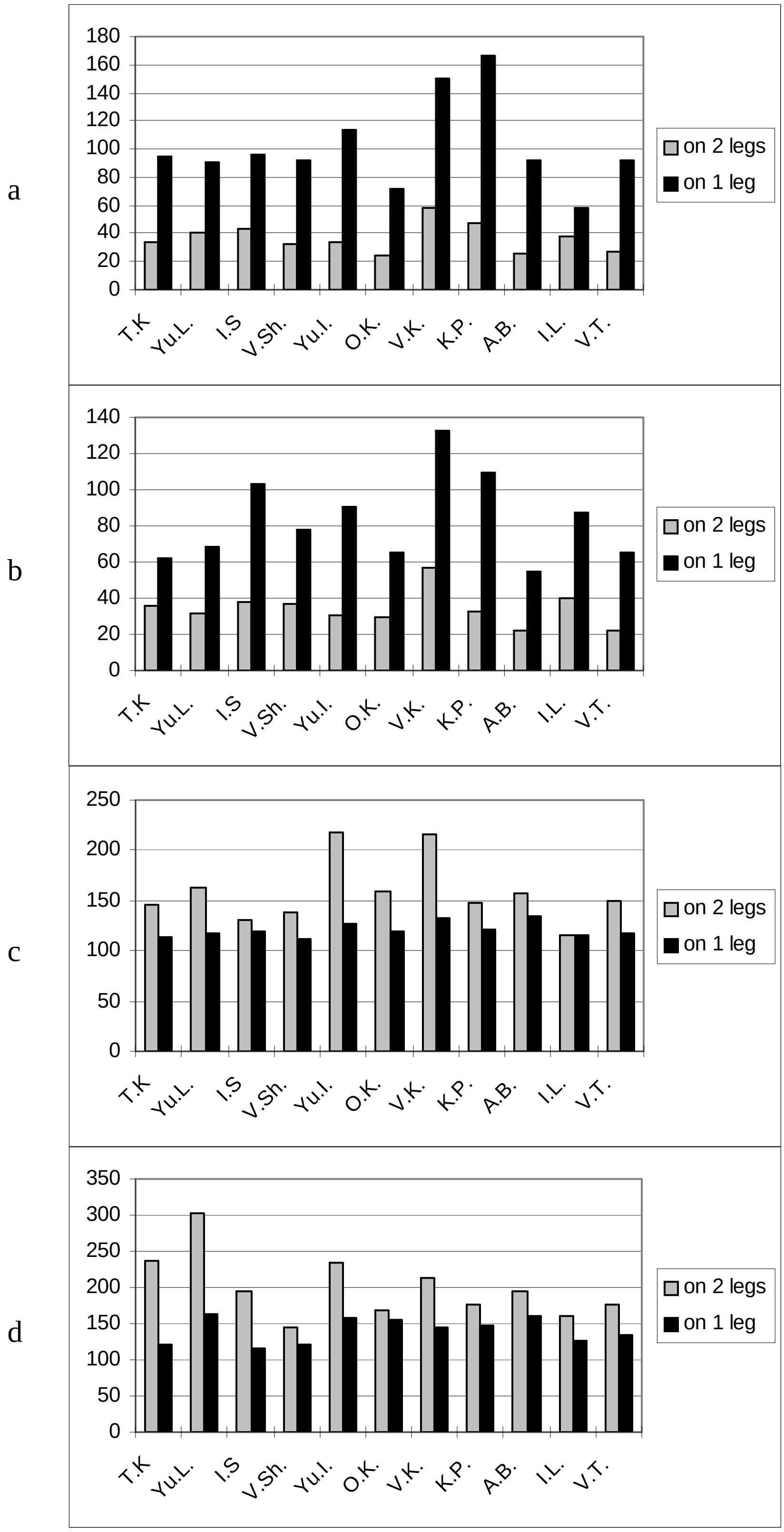

Fig.3. Frontal and sagittal stabilogram lengths before vibration (in cm) and during vibration (in % to initial length before vibration) during usual standing and standing on one leg: a, b – the lengths of frontal and sagittal stabilograms before vibration (in cm); c, d – The lengths of frontal and sagittal stabilograms during vibration (in % to the length before vibration).

system disturbance decreases with increase of posture instability. More prominent differences between vibratory effects in usual bipedal standing and standing on one leg, observed in preliminary experiments [4], could be explained by the fact that initially pedestals for subject's feet were narrower and shorter (8x30 cm instead of 18x40 cm in present work). Thus, in [4] the posture was even less stable than in current study.

It is known that postural effects of vibration could be modified by numerous factors, such as degree of voluntary control, alertness level, etc. So one could suggest that character of responses to vibration changed because subjects were habituated to the experimental situation. It may be expressed in the progressive (from trial to trial) increase of the CGP shift in response to vibration, while standing on one leg. We did not observe such effects.

Long ago Du Bois-Reymond [6] found that the «active» support surface during standing was restricted to contour situated inside feet perimeter at 3 cm distance. While standing on one leg the active support surface decreased more than twice.

It is worth noting that even the gain of monosynaptic stretch reflex arc may be controlled independently on the level of synapses between 1a-afferents and motoneuron's endings and by modulation of muscle spindle sensitivity through gamma-system. So it could be conjectured that on unstable support either proprioceptive information from muscle spindle is blocked or these afferent signals reach higher levels of the central nervous system, but their motor effects, mediated by spinal reflexes, are suppressed. The known data for enhancement of stretch reflex thresholds in orthograde posture [7] are in favor of hypothesis for inhibition of reflexes. It was shown that walking on narrow (3.5 cm) bar suppressed H-reflex [8] (its value decreased by 40 % in comparison with its value during walking on treadmill).

It should be noticed that the whole body tilt due to shank muscles vibration most likely is not mediated by the level of segmental reflexes. In unstable posture we have seen the decrease of vibratory effects both on the mean body position and on the dynamics of equilibrium maintenance. So in unstable posture changes in mechanisms of utilizing proprioceptive information take place both on spinal and supraspinal levels. At the moment it is difficult to answer what is the mechanism of these changes, supplementary experiments are necessary for obtaining more certain response to this question.

The other question, raising in connection with vibratory stimulation experiments, concerns the validity of the initial postulate that afferent activity evoked by vibration is identical to natural afferentation, arising during muscle stretch. It should be stressed that afferent activity elicited by vibration is marked by synchronous activity of different afferents, by the same frequency in different afferents and by constancy of this frequency in time. In addition artificial stimulation could be characterized by inconsistency of inflow from dynamic and static spindle endings and by altered relationship between signals of agonists and antagonists. It cannot be excluded that utilizing some of these features the central nervous system could distinguish natural signal against the background of artificial one or, if the signal appears erroneous, substitute it with afferentation from other muscles, for example, from antagonists.

Recently the hypothesis postulating two-level structure of the system of orthograde posture maintenance was proposed [9]. The lower level – the level of operative control – keeps CGP within a small area surrounding the referent point (projection of kinesthetic vertical) set by the higher level.

Within the frame of this hypothesis it could be supposed that shift of CGP reflects change of referent position, and curve lengths changes – the changes of quality of regulation around this referent position. In both cases effect of vibration was less pronounced in unstable position.

The results obtained show that the importance of proprioception in the elaboration of referent vertical in unstable posture is diminished. Besides that, the decrease of relative curve length augmentation during vibration in unstable posture gives evidence in favor of assumption that under these conditions the importance of proprioception for postural control diminishes also on lower level of current regulation.

When standing on one leg the system probably preferably uses visual and vestibular information and also information from muscles-antagonists.

Bell wrote [10] that in usual conditions, i.e. on both legs, we even did not know, how we stand. Only when standing on the narrow support or on one leg we began realize our body position. Apparently, transition from automatic equilibrium maintenance to conscious one is the main reasons of differences in reactions on vibratory perturbations.

Conclusions

The vibration-induced postural disturbances were markedly reduced in unstable posture relative to stable posture.

The use of postures with different stability may represent the useful instrument for study of the role of proprioceptive, visual and vestibular information in the maintenance of a human orthograde posture and elaboration of referent position serving as a set point for current control of equilibrium.

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СРАВНЕНИЕ ЭФФЕКТОВ ВИБРАЦИОННОЙ СТИМУЛЯЦИИ МЫШЦ ГОЛЕНИ ПРИ СТОЯНИИ НА ОДНОЙ И ДВУХ НОГАХ

Т.Б. Киреева, Ю.С. Левик (Москва, Россия)

Исследовали влияние вибрационной стимуляции проприоцепторов мышц голени на работу системы поддержания равновесия в двух позах с разной устойчивостью: при обычном стоянии и стоянии на одной ноге.

12 практически здоровых испытуемых стояли с открытыми глазами на установленных на стабилографе подставках. При стоянии на одной ноге одну подставку убирали, и неопорная нога свободно свисала. Вибрировали сухожилие камбаловидной или передней большеберцовой мышцы одной ноги с частотой 30 Гц и амплитудой 0.8 мм.

Вибрация сухожилия на одной ноге при стоянии на двух ногах вызывала такое же отклонение тела, как и вибрация сухожилий на двух ногах.

В неустойчивой позе при стоянии на одной ноге эффект вибрационной стимуляции был заметно меньше, чем в устойчивой позе. По-видимому, в неустойчивой позе больше используется зрительная и вестибулярная информация и информация от мышц-антагонистов. Позы с разной устойчивостью можно использовать для исследования роли проприоцептивной, зрительной и вестибулярной информации в процессе текущего регулирования вертикальной позы человека и формирования референтного положения, относительно которого осуществляется поддержание равновесия. Библ. 10.

Ключевые слова: ортоградная поза, положение равновесия, позы с разной устойчивостью, вибрация, проприоцепция

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