Maintenance of Equilibrium during Tracing Eye Movements

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Horizontal tracing movements of eyes modify the type of vertical posture maintenance decreasing the role of the lower segment in the regulation of the position of the pressure center. The relationship between fluctuations of the pressure center in the frontal and sagittal planes increases. Periodicity of eye movements corresponds to fluctuations of the pressure center and these signals were phase shifted relatively to each other.

Key Words: *vertical posture; tracing movements of the eyes; body segments*

Despite numerous investigations of the vertical posture regulation, higher levels of this regulations remain little studied, specifically, the effects of mechanisms of spatial orientation on the process of posture maintenance. We studied the maintenance of equilibrium during tracing eye movements (TEM), which by themselves cause no changes in the position of the mass center, but are closely related to the mechanisms of spatial orientation.

The effects of TEM on the posture are usually studied by analyzing the range of stabilogram fluctuations. In a pioneer study of equilibrium maintenance [2] the effects of eye tracing of a big pendulum moving with a frequency of 48 oscillations/min (0.8 Hz) were analyzed. Tracing caused an increase in the range of fluctuations in the majority (89.5%) of observers (by 109% in the frontal and by 54% in the sagittal plane). However, the effect of tracing on equilibrium maintenance is not so clear [4]. Tracing of a visual target moving at a frequency of 0.5 Hz caused an increase in the amplitude of body fluctuations in only 17% observers; in 3% this amplitude decreased, and in 79% cases the effect was null. No significant correlation between pressure center movements and eye movements or eye and head movements were detected [8], but the coefficient of correlations between pressure center movements and head movements was >0.6. On the other hand, averaged data indicated pressure center and head movements "parallel" to eye movements, but with a phase delay [8].

The study of TEM effects on the maintenance of vertical posture were carried out by the traditional methods of stabilogram analysis. We used another approach and analyzed the equilibrium maintenance within the framework of a two-component model of upset pendulum, when human body can be presented as consisting of two segments "hinged" with the hip joint.

MATERIALS AND METHODS

The experiments were carried out in 9 volunteers aged 22-53 years without known motor and visual disorders. Two volunteers were tested twice in order to control the data reproduction.

Three variants of the experiment were carried out: tracing of a visual stimulus moving along a sinusoidal trajectory with 0.1 and 0.01 Hz frequencies (rapid and slow TEM) and fixation of a visual target situated directly in front of the volunteer (control). The volunteers traced horizontal movements of a visual stimulus (0.2 angular grades in diameter) on a cylindrical screen occupying the entire visual field. The stimulus movements were provided by signal transfer from G6-15 generator of low frequency signals to the entry of a voltmeter with a light mirror (3×3 mm) fixed on the axis. The ray from a laser pointer was projected to the

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mirror. The amplitude of the stimulus movements was ±35 angular grades to the right and left at the level of volunteer's eyes. The experimental room was dark. The duration of each recording was 2 min.

The horizontal component of TEM was recorded on an electrooculogram, the frontal and sagittal components of the pressure center transpositions were recorded on a stabilographer (stabilograms), and transpositions of the upper and lower segments (US and LS, respectively) of the body in the frontal plane were recorded using tensometric pickups (mechanograms). Mechanograms were recorded in points lying at the crossing of the median spinal line and axes of the hip and arm joints rotation in the frontal plane. All joints except the talocrural and hip ones were fixed by means of battens fixed to the body: two battens fixed the knee joints and the third was fixed on the median line of the spine, providing fixation of the head position on the trunk and spine.

Signal processing included analysis of the amplitudes of stabilogram and mechanogram oscillations and of the relationship between the recorded signals (coefficients of correlations and cross-correlation functions (CCF)). The significance of differences was evaluated using Student's *t* test and paired Wilcoxon's test.

RESULTS

In order to detect specific features in the maintenance of equilibrium during TEM, we analyzed the coefficients of correlations between the trajectories of the pressure center, between US and LS in the frontal plane and TEM. Relationships between the trajectories of US and LS transpositions were high and statistically did not differ in all volunteers under all conditions of recording (Table 1). TEM was an essential factor for correlations between the trajectories of body segments and pressure center transpositions. Coefficients of correlations during TEM were lower than during fixation. A statistically significant decrease of coefficients of correlation between transpositions of US, LS, and pressure center in the frontal plane *vs.* the control was observed during slow TEM. In addition, coefficients of correlations between LS transposition and frontal stabilogram during fixation and rapid TEM differed significantly (Wilcoxon's paired test).

Coefficients of correlation between the trajectories of US and LS transpositions and the sagittal stabilogram were also significantly lower during TEM than during fixation (Wilcoxon's paired test). Coefficients of correlation between US fluctuations and frontal stabilogram were significantly higher than coefficients of correlation between LS fluctuation and frontal stabilogram. The relationship between the frontal and sagittal components of stabilogram increased during tracing (Table 1).

It seems that decreased relationship between the trajectories of body segments transpositions and stabilogram, observed during TEM, reflects changed regulation of the posture during tracing. As in our experiments the transpositions of US and LS were recorded at the points of spinal median line crossing with the arm and hip joint axes, the trajectories do not fully reflect the fluctuations of the points situated near the joint rotation centers. Presumably, torsion movements emerging in TEM modify the stabilogram. These movements result in a stronger relationship between the frontal and sagittal components of the stabilogram. The relationship between US fluctuations and frontal stabilogram is stronger than between LS fluctuations and frontal stabilogram, which suggests that the effect of the lower segment on transposition of body pressure center decreased during TEM.

The relationship between the frontal component of stabilogram and TEM increases during TEM (coefficients of correlations virtually do not differ from the

TABLE 1. Coefficients of Correlation between the Recorded Signals (n=11; $M\pm m$; p=0.05)

Parameter	Tracing		Fixation
	slow	rapid	
Frontal stabilogram—sagittal stabilogram	0.12±0.12*	0.11±0.12	-0.05±0.13
Frontal stabilogram—transposition of body LS	0.82±0.05*	0.89±0.05*	0.93±0.03*
Frontal stabilogram—transpositions of body US	0.85±0.04*	0.91±0.05*	0.94±0.02*
Transpositions of body LS—transpositions of body US	0.98±0.02*	0.98±0.01*	0.99±0.01*
Transpositions of body LS—sagittal stabilogram	-0.05±0.10	-0.02±0.16	-0.22±0.16*
Transpositions of body US—sagittal stabilogram	-0.06±0.10	-0.05±0.14	-0.22±0.16*
Frontal stabilogram—eye movements	0.14±0.14*	0.19±0.12*	0.06±0.17
Sagittal stabilogram—eye movements	0.08±0.12	0.00±0.07	0.03±0.12

Note. *Significant difference from the zero.

zero in the control but differ during TEM). The mean coefficients of correlations are very low (0.14 for slow and 0.19 for rapid TEM). Presumably, low values of correlation coefficients can be due to different delay of reactions to tracing for eye movements and body movements. Cross-correlation analysis showed that the CCF peaks were shifted *vs.* the zero (Figs. 1, 2).

The maximum and minimum CCF values alternate during rapid TEM for pairs: frontal components of stabilogram—horizontal movements of the eyes and

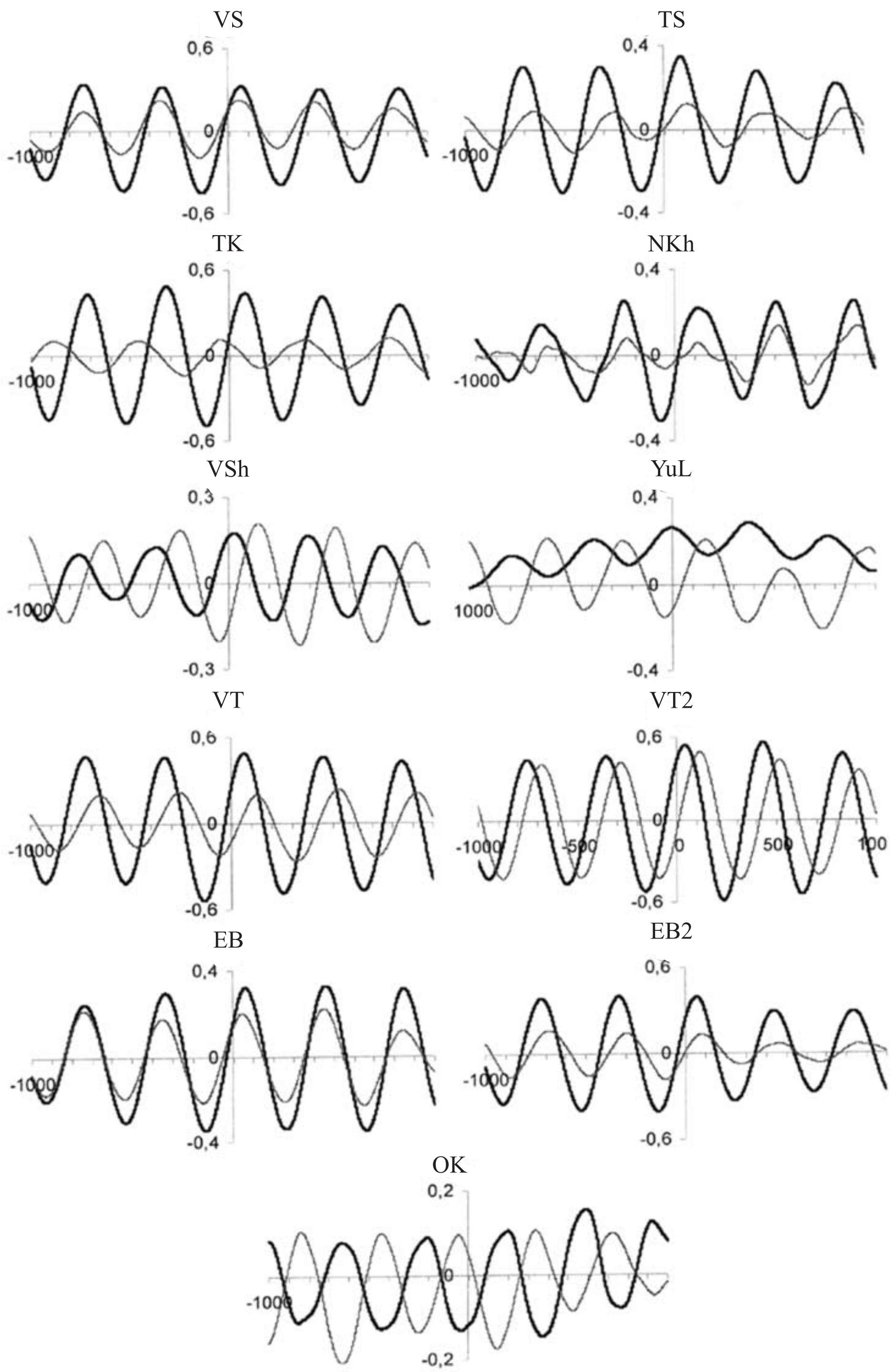

Fig. 1. Cross-correlation functions between fluctuations of the pressure center in the frontal (bold lines) and sagittal (thin lines) planes and eye movements during rapid tracing for different volunteers. Here and in Fig. 2: abscissas: shift of eye movement trajectory *vs.* trajectory of pressure center transposition in bines (maximum 1000 bine shift corresponds to 25 sec); ordinates: coefficient of correlation.

for sagittal components of stabilogram—horizontal movements of the eyes (Fig. 1). This indicates that tracing of the visual stimulus movement in the horizontal plane induces the emergence of body fluctuations in all volunteers with the same periodicity as TEM both in the frontal and sagittal planes. Fluctuations in the frontal plane were more pronounced than in the sagittal plane in the majority of volunteers, which is natural during tracing of a horizontal movement of a stimulus in the frontal plane.

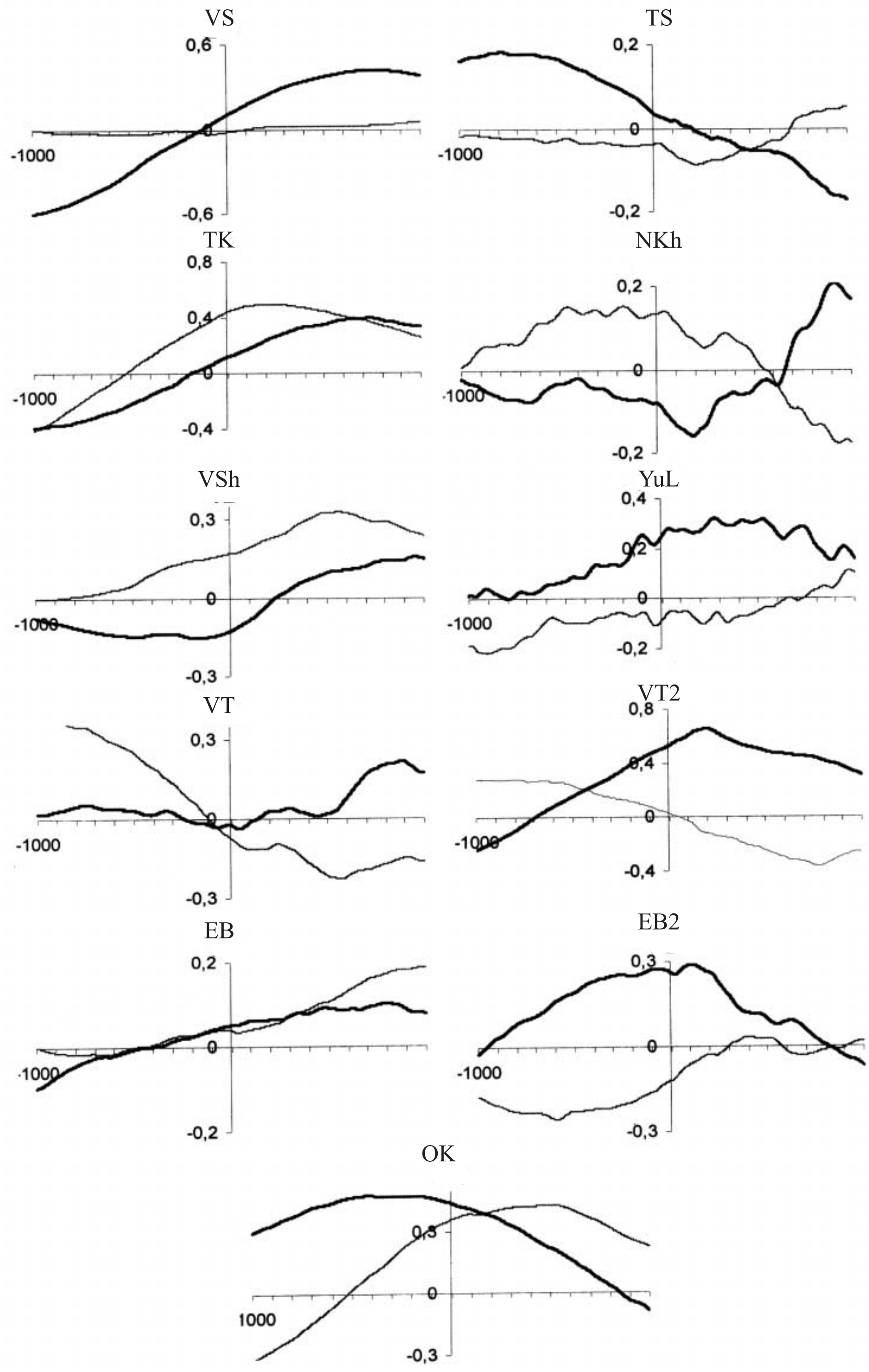

Fig. 2. Cross-correlation functions between fluctuations of the pressure center in the frontal (bold lines) and sagittal (thin lines) planes and eye movements during slow tracing for different volunteers.

TABLE 2. Maximum Coefficients of Correlations according to CCF of Stabilogram Components—Eye Movement Signals (*M*±*m*)

Volunteer	Frontal stabilogram—eye movements		Sagittal stabilogram—eye movements	
	rapid tracing	slow tracing	rapid tracing	slow tracing
VS	0.33	0.42	0.23	0.04
TC	0.35	0.18	0.12	0.05
TS	0.48	0.40	0.13	0.49
YuL	0.28	0.32	0.20	0.11
VSh	0.17	0.14	0.21	0.33
NKh	0.25	0.21	0.13	0.15
VT	0.49	0.22	0.21	0.39
VT2	0.56	0.66	0.46	0.27
EB	0.32	0.10	0.21	0.19
EB2	0.38	0.29	0.17	0.03
OK	0.15	0.48	0.20	0.43
Mean	0.34±0.08	0.32±0.10	0.21±0.06	0.23±0.11

The CCF maximum was shifted from the zero in virtually all volunteers and the frontal stabilogram—eye movements and sagittal stabilogram—eye movements CCF were shifted one *vs.* the other. In some cases this shift was slight (Fig. 1, VS, NKh, EB), in other cases the functions were in the counter phase (Fig. 1, OK). These three cases are examples of predominance of the diagonal fluctuations of the body during TEM, that is, the shift of the pressure center to the left (or right) is paralleled by a simultaneous shift to the front (or backward). These functions were shifted one *vs.* the other by less than half-period in the majority of volunteers, which seems to indicate the predominance of ellipsoid trajectories.

No alternation of maximums and minimums, characteristic of CCF during rapid TEM, was observed during slow TEM (Fig. 2). This was due to the fact that just less than one oscillation period occurred during the entire period of recording (2 min).

The mean values of maximum coefficients of correlations in CCF between the stabilogram components and signals of eye movements during slow and rapid TEM were the same (Table 2).

A possible cause of changes in the maintenance of equilibrium during TEM following a visual stimulus moving in a horizontal plane is striving to escape great angles of eye deviation from the central position. The so-called eye centration system [1] maintains eye centration in the orbits during ocular movements, that is, providing eye return into the “directly in front” position (position involving the minimum activity of oculomotor muscles).

The amplitude of the visual stimulus was rather long (35^o to the right and left from the central position). Deviations of the eye in the temporal direction (to the right for the right eye and to the left for the left one) varied within 40-55^o, depending on the individual characteristics of a volunteer. If it were possible to trace the stimuli by moving the head, the tracing would have been realized by coordinated movements of the eyes and head. In our experiment the head was fixed to the trunk so that it was impossible to turn it, and tracing was realized by coordinated movements of the eyes and US.

Orientation synergisms belong to the repertoire of basic mechanisms responsible for navigation of man [5]. Presumably, this orientation of the US in the direction of the glance movement helps in the formation of a stable reference system essential for programming and realization of movements. Vibration of the cervical muscles causes acceleration of man’s movements in the direction of the glance [6]. If the head is fixed in the space without visual control, slow torsion movements of the neck [3] and other compartments of the spine can cause illusion of head or entire US turning, these illusion being associated with high-amplitude movements of the eyes towards the illusive movement. Reverse effects of TEM on the tone of body muscles are also possible: the effects of vibration of oculomotor muscles on the body position of a standing man have been demonstrated [7], which led to conclusion on the involvement of the proprioception from ocular muscles in the production of the reference late vertical.

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