The effect of transcutaneous electrical stimulation of the cervical spine on the postural stability of a healthy person

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Abstract - **Transcutaneous spinal cord stimulation (tSCS) is a non-invasive method of painless electrical exposure. In experimental models of intact and damaged CNS, it has been shown that tSCS can facilitate intra-spinal neural plasticity and can be used to restore motor function. The aim of this study was to evaluate the effect tSCS at the C5-C6 level different frequency on postural stability of healthy individuals. The study was conducted on 11 healthy participants. A stabilographic sample was recorded before, during tSCS of the cervical vertebrae and after stimulation. In total, 3 stages were held: when participants stood on a solid surface with their eyes open and closed, when standing position on an unstable surface with their eyes open. The intensity of stimulation was 90% of the response threshold in the muscles of the upper extremities, the frequency was 20 Hz and 30 Hz, the stimulation area was between the C5-C6 vertebrae. It was shown that the statokinesiogram area, velocity of body sway, length, the trajectories of the pressure center and the deviation in the frontal and sagittal planes decreased with SCS, the quality of the equilibrium function increased in all three stages. When stimulated with both a frequency of 20 Hz and 30 Hz, a significant decrease in the power of the high-frequency region of the spectrum was obtained at all three stages. A decrease in the power of the high-frequency region of the stabilogram spectrum against the background of an improvement in classical and vector parameters is a positive effect of stimulation on postural stability. Probably, the positive effect of tSCS is based on a downward facilitating effect on the postural muscles of the lower extremities.**

Keywords—transcutaneous electrical spinal cord stimulation, stabilography, postural stability, human.

I. INTRODUCTION

The spinal cord is the center of integration of descending, ascending and segmental neural signals and stimulation at various levels can modulate intra-spinal connections [1, 2]. It has been shown that transcutaneous spinal cord stimulation (tSCS) on C5-C6, Th11-Th12 and L1-L2 can improve the quality of walking in healthy subjects and cause involuntary step movements [3-5]. tSCS at a higher intensity (> 80 mA) at a level of Th10-Th11 activates the musculature of the trunk, which helps maintain posture [6]. In our study, when using the Jendrassik maneuver, it was shown that tSCS at the cervical level caused a decrease in the threshold of excitation of α-motor neurons, mediated by a change in their background activity [7]. The preservation of a well-coordinated fictitious locomotor pattern in the spinal cord in vitro indicates that the coordination of quadrupedal limbs in mammals is largely mediated by propriospinal connections between the cervical and lumbar generators. Activity in one generator depends on activity in the other, thus mediating coordination between the limbs [8]. The connection between the limbs becomes clear, probably through long propriospinal connections that connect the cervical and lumbar neural networks [9]. Of particular importance is the fact that the basic nervous mechanisms in bipeds and quadrupeds are common, the neural circuits underlying bipedal locomotor rhythmicity are not limited to a specific area of the spinal cord but extends from the lumbar to the cervical levels [10, 11].

We hypothesized that the subthreshold tSCS of the cervical spine can activate propriospinal pathways which, in turn, can affect the activity of the lumbosacral motor neural network, modulating systems for maintaining postural balance. The aim of this study was to evaluate the effect tSCS at the C5-C6 level different frequency on postural stability of healthy individuals.

II. METHODS

The study involved 11 apparently healthy subjects aged 18 to 27 years without motor and neurological disorders. Postural stability was assessed using the stabilometry method. A stabilometric test was recorded using a computerized platform with biological feedback "Stabilan-01-2" (Taganrog). Signal processing was performed in the program itself. The subjects to stand on the centre of the platform in a neutral position, with his arms along his sides and the feet apart of 30° and heels spaced 2 cm from each other.

The classic, vector stabilometric parameters were registered: Statokinesiogram area (S), mm2; Qx and Qy - Root mean square distance in frontal (X) and sagittal (Y) plane, mm; LX and LY -Trajectory length in frontal (X) and sagittal (Y) plane, mm; Quality of the Equilibrium Function, %; Velocity of body sway, mm / sec. An increase in the values of these parameters indicates deterioration in stability, an increase the Quality of the Equilibrium Function - an improvement in stability. The spectral components of the stabilometric signals were determined via of computer program: Pw1 (F) – spectral power of stabilogram in the first zone in the frontal planes, Pw2 (F) – spectral power of the stabilogram in the second zone in the frontal planes, Pw3 (F) – stabilogram spectral power in the third zone in the frontal

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planes; Pw1 (S) – spectral power of stabilogram in the first zone in the sagittal planes, Pw2 (S) – spectral power of the stabilogram in the second zone in the sagittal planes, Pw3 (S) – stabilogram spectral power in the third zone in the sagittal planes. The spectrum of stabilograms is divided into three zones: the zone of very low frequency (0 - 0.2 Hz) - characterizes the fluctuations of the subject's center of pressure (COP) associated with slow, often uncontrolled, postural control processes; low frequency zone (0.2 - 2 Hz) - characterizes the oscillations of the subject's COP associated with the regulation of posture; the high frequency zone (2 - 6 Hz) - characterizes the oscillations of the subject's COP associated with physiological processes, tremors.

A BioStim-5 (Cosyma Inc., Moscow, Russia) five-channel stimulator was used for transcutaneous electrical stimulation of the spinal cord. The stimulating round electrode (cathode) was located between the C5 and C6 vertebrae, rectangular electrodes (anode) were located bilaterally over the clavicles. To determine the parameters of stimulation, the threshold for the emergence of responses in the muscles m. Flexor carpi ulnaris, m. Extensor carpi radialis was determined. The stimulus intensity was selected individually according to the threshold for the occurrence of muscle responses and amounted to 90% of the threshold value. The stimulation frequency was 20 and 30 Hz, the pulse duration was 1 ms. A Neuro-MEP-8 (by Neurosoft Company, Russia) was used to record muscle activity.

The research was conducted on different days. On the first day, the tests were taken with open eyes. A stabilometric test for 1 min was recorded before stimulation. Then, stimulation was performed at 20 Hz for 3 min and a stabilometric test was recorded; after stimulation, a stabilometric test was recorded for 1 min. After the test, the subjects rested for 10-15 minutes, and then these stages were conducted with stimulation at a frequency of 30 Hz. On the second day, the recording of the stabilometric test and stimulation were performed with eyes closed (n = 7). A stabilometric test for 1 min was recorded before stimulation. Then, stimulation was performed at a frequency of 20 Hz for 3 min and a stabilometric test; after stimulation, a stabilometric test was recorded for 1 min. After the test, the subjects rested for 10-15 minutes, and then these stages were conducted with stimulation at a frequency of 30 Hz. On the third day, the study was carried out with eyes open on the unstable surface (n = 6). A unstable surface was cushions made of foam rubber (18 cm high), the cushions were placed on a stabilometric platform. A stabilometric test for 1 min was recorded before stimulation. Then stimulation was performed at a frequency of 20 Hz for 3 min and a stabilometric test; after stimulation, a stabilometric test was recorded for 1 min. After the test, the subjects rested for 10-15 minutes, and then these stages were carried out with stimulation at a frequency of 30 Hz.

The obtained data are presented as arithmetic mean and standard deviation. The statistical analysis was performed with the nonparametric Wilcoxon test, the significance level was set at $p < 0.05$.

III. RESULTS

Before stimulation, when standing position on an unstable surface, significant changes in the stabilographic parameters were observed ($p<0.05$): the area of the statokinesiogram, the length of the trajectory (X, Y), the rate of rocking of the body, the RMS distance (X) increased, the quality of the equilibrium function decreased.

Stimulation with a frequency of 20 Hz in a stand position with open eyes led to an improvement in several indicators of classical and vector stability ($p < 0.05$): during stimulation, the quality of the equilibrium function (%) increased (Fig.1), the rate of body rocking decreased (Fig.2, B). The length of the trajectory (X, Y) was increased during stimulation ($p < 0.05$), (Fig.2, A). At TSCs of 30 Hz (Fig.1), the area of the statokinesiogram and the length of the trajectory (X, Y) increased.

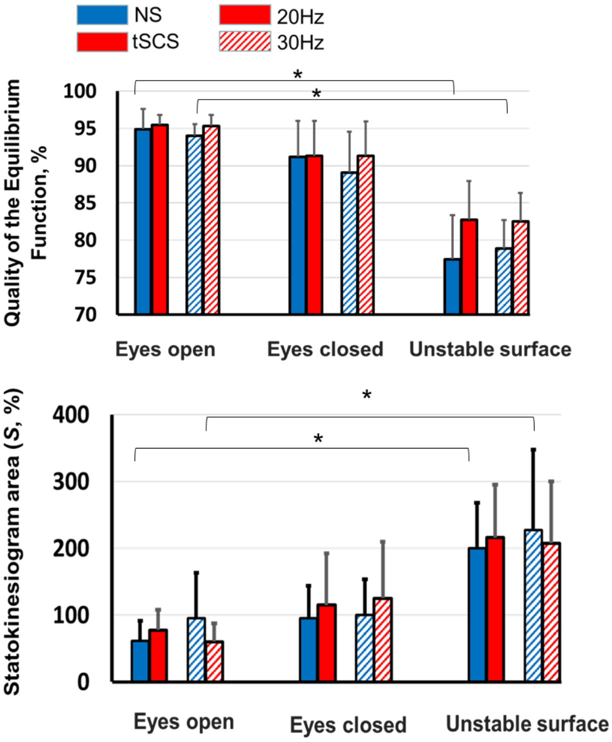

Fig.1 Statokinesiogram area and Quality of the Equilibrium Function on 20 Hz and 30 Hz stimulation with open eyes, close eyes and unstable surface; dotted line is non-stimulation (NS), *<0,05 – differences between non-stimulation and with stimulation (tSCS)

Stimulation of 20 Hz with closed eyes led to the following results: during stimulation the Statokinesiogram area, the Trajectory length (X, Y) increased, the Velocity of body sway decreased (Fig.2). With closed eyes during stimulation of 30 Hz the Statokinesiogram area, the Trajectory length (X, Y) increased ($p < 0.05$), the Velocity of body sway decreased (Fig.2). According to the resulting indicator of the Quality of the Equilibrium Function in conditions of deprivation of vision, it can be seen that the value of the indicator increased during tSCS and remained enlarged after the stimulation.

On the unstable surface during stimulation the Trajectory length (X, Y) increased at both frequencies of stimulation. During the stimulation a decrease in Velocity of body sway was obtained. During 30 Hz stimulation the Statokinesiogram area, Velocity of body sway, Root mean square distance (X) decreased. The Quality of the Equilibrium Function increased during stimulation.

Analysis of the spectrogram of postural oscillations before stimulation showed that most of the postural oscillations had a low frequency (less than 1 Hz); more high-frequency fluctuations in the center of pressure (COP) (2-6 Hz) were observed in all subjects and in all mentioned conditions, but their total power (TP) in the overwhelming majority did not exceed a few percent of the total power of the entire spectrum. In the position of open eyes on a solid surface, with visual control, the TP of oscillations (less than 0.2 Hz, Pw1) in the frontal and sagittal planes averaged 38 ± 14% and 39 ± 14.7% of the total power of the respective spectra.

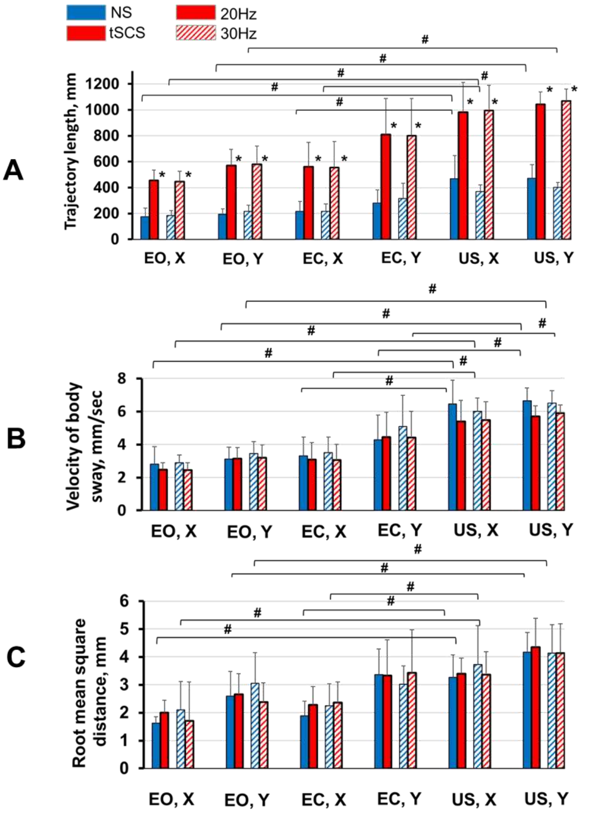

Fig.2 A - Trajectory length (X, Y), B - Velocity of body sway decreased, C - Root mean square distance (X, Y on 20 Hz and 30 Hz stimulation with open eyes (EO), close eyes (EC) and unstable surface (US); *<0,05 – differences between non-stimulation (NS) and with stimulation (tSCS), #<0,05 – differences between EO, EC and US in non-stimulation

At tSCS with a frequency of 20 Hz, the spectral composition of the stabilogram changed. At tSCS, an increase in the relative contribution of very low frequency (less than 0.2 Hz, Pw1) in the frontal plane ($p < 0.05$) was observed, with a simultaneous increase in low-frequency oscillations (0.2-2 Hz, Pw2) (Fig. 3A).

The differences of the corresponding averages were not reliable (due to the high dispersion of individual values), but the tendency looked quite clear. The situation with the sagittal oscillations also was similar. (Fig. 3B). tSCS 20 Hz caused a significant decrease in the share of relatively high-frequency postural oscillations (2.0-6.0 Hz, Pw3). The averaged normalized power of the specified high-frequency part of the spectrum of frontal and sagittal oscillations in the conditions of open eyes on solid surface during stimulation of 20 Hz decreased to 4% of the total power ($p <0.05$).

For comparison, the corresponding proportion of high-frequency front and sagittal oscillations in conditions without stimulation was 10% (Fig. 1). With the tSCS 30 Hz in relation to frontal and sagittal oscillations, the situation was similar, with the exception of the low-frequency range (0.2-2 Hz). When stimulating 30 Hz in the open eyes position on a solid surface, the PW2 oscillations in the frontal and sagittal planes were an average of 53 ± 14% and 50 ± 15% of the total power of the corresponding spectra (Fig. 3A, B).

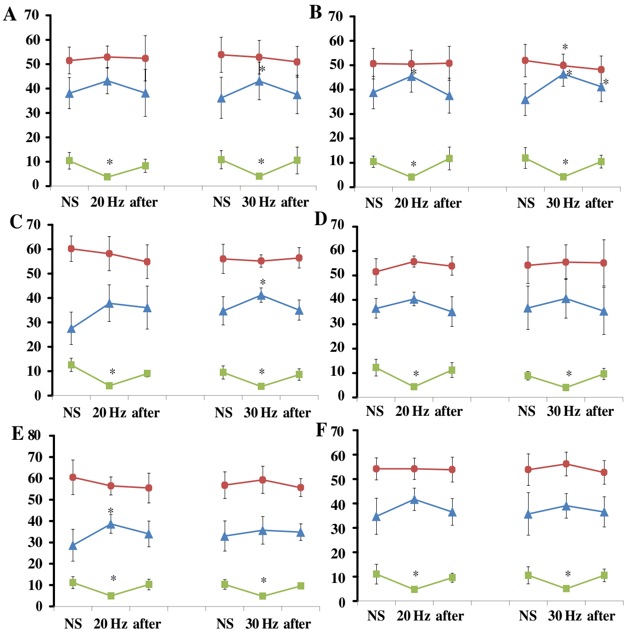

Fig.3 Spectral parameters of stabilographic signal; triangle - very low frequency oscillations of the COP (0 - 0.2 Hz), circle - low frequency oscillations of the COP (0.2 - 2 Hz), square - high frequency oscillations of the COP (2 - 6 Hz); A,C,E – frontal plane, B,D,F – sagittal plane; *<0,05 – differences between non-stimulation (NS) and with stimulation (20 Hz / 30 Hz)

When deprivation of view (closed eyes on solid surface) a decrease in the relative contribution of the very low frequencies (up to 0.2 Hz, Pw1) fluctuations in the frontal plane and the simultaneous increase in the share of the low-frequency range (Pw2, from 0.2 to 2 Hz) to 60 ± 9% (Fig.3, C). During the stimulation of 20 and 30 Hz, the restoration of the ratio of very low and low-frequency oscillations of the COP, both in the frontal and in the sagittal planes and at the same time the tSCS was determined by a significant decrease in COP fluctuations in the high-frequency range ($p <0.05$; Pw3) (Fig. 3C, D).

With open eyes, the unstable surface, changing the ratio of different spectral power frequencies was similar to the conditions with their eyes closed. There was a decrease in the relative contribution of the very low frequencies (up to 0.2 Hz, Pw1) fluctuations in the frontal plane and the simultaneous increase in the share of the low-frequency range (Pw2, from 0.2 to 2Hz) to 61 ± 14% (Fig.3), changes in the sagittal plane were not observed. During the stimulation of 20 and 30 Hz, the ratio of very low frequency and low frequency oscillations of the COP, both in the frontal and the sagittal planes, and at the same time the tSCS was determined by a significant decrease in COP fluctuations in the high-frequency range ($p <0.05$; Pw3) (Fig.3).

IV. DISCUSSION

Balance control is based on accurate perception of visual, somatosensory, and vestibular signals [12]. The ability of spinal networks to independently carry out postural control, considering afferent input from the musculoskeletal system under conditions of additional tonic stimulation, is shown [13,14]. The combination of tSCS with locomotor training in patients with cerebral palsy was accompanied by a tendency to maintain the projection of the center of mass of the body in the sagittal plane in a normal position [15]. The results of our study showed that tSCS at the C5-C6 level can improve the quality of postural control in a healthy person both with visual control and in conditions of visual and proprioceptive deprivation.

The improvement in postural stability was more pronounced when stimulated at a frequency of 30 Hz. The neurons of the spinal cord are sensitive to the location, intensity, and frequency of stimulation [16]. For example, it has been demonstrated that stimulation at the level of Th11–Th12 with a frequency of 30 Hz is more specific for facilitating rhythmic step movements [17], while stimulation of L1-L2 with a frequency of 15 Hz leads to the facilitation of tonic extensor activity characteristic of postural control [18].

An increase in the very low frequency spectrum zone during stimulation (with eyes open, on a solid surface) may indicate a connection to the regulation of the visual-vestibular system and an increase in the unconscious mechanisms of postural stability [19]. With closed eyes, this effect was obtained with 30 Hz stimulation for the frontal plane and on a unstable surface with 20 Hz stimulation for the sagittal plane. In the sagittal plane, in the test with open eyes after stimulation, a decrease in the power of very low and low frequency zones was obtained, which may relate to a decrease in the participation of the visual-vestibular and cerebellar systems in the regulation of postural stability [19]. During stimulation with both a frequency of 20 Hz and a frequency of 30 Hz, a significant decrease in the power of the high-frequency zone was obtained at all three stages of the study. A decrease in this parameter may indicate a decrease in arbitrary fluctuations of subjects [19].

In general, a decrease in the power of the high-frequency region of the spectrum of stabilograms, along with an improvement in classical and vector stabilometric parameters, indicates a positive effect of tSCS on human postural stability. The improvement of postural stability in the presence of tSCS maybe related to the ability of sensorimotor networks to effectively use and converge descending pathways and proprioceptive inputs to create patterns of motor activation necessary to maintain equilibrium [13]. The use of cervical spine tSCS in the rehabilitation of patients with problems maintaining postural stability can improve this function, as we have shown in this study on healthy participants.

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