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STUDY OF THE CYCLIC ELECTRICAL STIMULATION METHOD FOR PREVENTION OF SLEEPINESS PAROXYSMS DURING A MONOTONOUS ACTIVITY[1]

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The problem of uncontrolled falling asleep during a monotonous activity while driving, on alert, in the workplace, or other similar environments has not been solved yet and remains a relevant issue. The paper presents the results of an experiment aimed at assessment of the effectiveness of cyclic electrical stimulation for maintenance of the conscious state and counteraction against sleepiness paroxysms carried out using the cyclic electrical stimulator CES-1 manufactured by SpecTechPro Company (with I. A. Rybachenko as the head of the project). The experimental design included modeling the monotony state with and without electrical stimulation, assessment of the participants' subjective state, EEG, HRV and reaction time analyses. The sample involved 31 subjects. The results of subjective scaling reliably demonstrate that electrical stimulation significantly (over 1.5 times) reduces participants' reportable signs of decreased wakefulness. There were no marked changes in the EEG, heart rate variability, and reaction time found.

Key words: electrical stimulation, monotony, electroencephalography, heart rate variability, subjective scaling

The development of the monotony state is a serious issue in various fields of human activities – while driving a vehicle, on alert, while operating conveyor systems, semiautomatic and automated systems, during continuous tracking assignments carried out by controllers, during sport activities, while reading complex literature, documenting and analyzing undifferentiated data, attending lectures, concerts, public events, etc. Advanced stages of this state are especially hazardous, causing involuntary sleep, which results in high trauma rates and casualties in potentially risky activities.

A. Cubser (1968) defined monotony as "the state of decreased mental alertness manifest in increased fatigue and sleepiness which results in a decreased ability to respond, switch activities, as well as in unstable and decreased work efficiency" [quoted in 13, p. 39]. According to A.B. Leonova, monotony is a functional state of human body arising from monotonous work. It is characterized by a decrease in the overall alertness level, loss of conscious control of activities, weakened concentration and short-term memory, insensitivity to external stimulating agents, prevalence of stereotyped movements and actions, subjective sensations of boredom, sleepiness, inertness, apathy, loss of interest for work [2]. Monotony as defined by L.P. Grimak is the state opposite to stress, which is characterized by a decreased level of vital activity arising from the influence of undifferentiated stimulants, that is decreased external stimulation [9]. Simultaneously, the last provided definition is inconclusive, as there exists evidence implying a specific type of stress arising exactly from monotony.

For instance, as shown by M.V. Gorbacheva and T.G. Kuznetsova, monotonous presentation of a stimulus, even a positive one, in subjects suffering from anxiety can lead to emotional strain, that is stress, which is demonstrated by the stress index dynamics in the heart rate variability analysis [3]. People affected by the monotony state complain of apathy, boredom, and strong reluctance to continue the activity that has caused it, which can also be

[1] The study was conducted at the instigation and with technical assistance of the SpecTechPro Company (Kharkiv, head of the project I.A. Rybachenko)

regarded as stress [9].

Monotony is diagnosed and studied using the methods of psychophysiology (EEG, EOG, EMG, EDR, heart rate assessment), behavioral reactivity assessment (reaction time) and psychodiagnostic methods and approaches [8, 14]. Australian researchers from the Centre for Road Safety and Accident Research (Larue G.S., Rakotonirainy A., Pettitt A.N., 2010) note that the most preferable psychophysiological method is EEG which must be combined with reaction time assessment and subjective state assessment [14]. G. Larue et al. provide the following classification of EEG correlates of functional states: anxiety is accompanied by a decrease in the alpha-activity and increase in beta-activity; sleepiness/fatigue is accompanied by lower alpha-activity and a dramatic decrease in beta-activity, higher theta- and delta-range manifestations. In the state of sleepiness, there are cycles of decreased and increased alpha-activity, increased theta- and delta-oscillations. In the state of fatigue, oscillations in the alpha and theta ranges increase. While performing monotonous tasks, alpha-activity becomes more pronounced in the frontal parietal areas. Microsleep paroxysms are accompanied by bursts of alpha- and theta-activity.

Acknowledging the importance of EEG-based tests, numerous authors highlight the necessity of monitoring non-electrical physiological indicators of wakefulness levels – indicators of hemodynamics, respiratory dynamics, body temperature variations, etc. [12].

Monotony prevention is traditionally achieved by applying various ergonomic methods of workspace management [13], signaling lamps and buzzers that a controller should react to by pressing the feedback button, devices for analysis of oculomotor reactions with audial feedback [6], biologically controlled electromagnetic stimulation [7, 12], using functional music, pharmacological means [8]. Based on literature review results, numerous specialists state that there are currently no satisfactory counteraction means against deterioration of performance quality for drivers on monotonous roads [14].

To the best of our knowledge, one of the psychophysiological methods, electrical stimulation, has not been previously used to address the monotony problem, although its applications in applied psychophysiology range from relaxation, treatment, and athletic training [13] to cosmetological routines [11].

Taking into account the circumstances, development and assessment of new methods of monotony counteraction, namely the electrical stimulation method, appear relevant.

Research objective is to assess the effectiveness of the hardware-based psychophysiological method of cyclic electrical stimulation of the forearm for prevention of monotony accompanied by sleepiness paroxysms.

Research tasks: 1) to diagnose the participants' functional state at the initial, interim, and final stages of the experiment; 2) to model the state of perceptual monotony using EEG; 3) to apply the method of cyclic electrical stimulation of the forearm during a monotonous activity; 4) to compare the indices of the participants' functional state at the experimental/control stages considering the factors of gender, age, experimental/control stage sequence, test time, previous night's sleep duration, amperage/voltage and frequency of the stimulating current, initial wakefulness/monotony level.

The **study sample** was composed of 31 participants (median age 32 years, age range 18-57 years), 11 females and 20 males, residents of Kharkiv city. All participants signed informed consent forms. The study was carried out February 5-14, 2014 at the Laboratory of psychodiagnostics of V.N. Karazin Kharkiv National University.

The following **methods** were selected in order to fulfill the research tasks:

1. Subjective scaling of a study participant's state: 5-point self-assessment of the participant's state using 12 monotony symptoms (indifference, lack of alertness, oscitation, lack of mental agility, reaction impromptness, stiffened face sensation, eyes closing sensation, decreased pulse and breathing sensation, numbness, "shutoff" sensation, lack of

readiness to act, drowsiness). A minimal score on the scale is 0 points, maximal 48 points.

2. The EEG method presupposes a single-channel bipolar EEG in the frontal parietal leads FCz (between Fz and Cz) and PCz (between Pz and Cz) according to the international system 10-20 with automated quantitative processing of magnitude indicators of the basic rhythms (delta 2, theta, alpha, beta 1, beta 2). EEG recording was carried out using the REAKOR apparatus (MEDIKOM MTD Company, Taganrog, Russian Federation). During the EEG recording a reference lead was used that was put on a subject's right arm [5].

3. Analysis of heart rate variability (HRV) within a time frame of 3 minutes in the sitting position, registration using the photoplethysmography method based on the software and hardware complex BOS-PULS (KOMPYUTERNYE SISTEMY BIOUPRAVLENIYA, Novosibirsk, Russian Federation) [1].

4. Computer-assisted method of reaction time assessment using the software and hardware complex BOS-PULS. The method was essentially a gaming simulation of vehicle driving during which it was necessary to press the Space bar in case if any obstacles arose within view.

5. The method of modeling the state of perceptual monotony involved demonstration of a slide show with nature views on the computer monitor display to a participant for 25 minutes (18 slides at the initial and final stages and 35 slides at the principal stage, each slide is demonstrated for 7 seconds, slide change time is 1 second) accompanied by slow-paced repetitious relaxation music. The slide show was implemented in the software shell of the REAKOR complex, which allowed recording EEG simultaneously. The slide show was organized as a three-staged demonstration – initial (2.5 minutes), principal (20 minutes), and final (2.5 minutes) for separate analysis of EEG characteristics at these stages. A participant was instructed to carefully study all the slides focusing on the screen only and not closing his/her eyes. The procedure was implemented twice – at the "experimental" step (with the cyclic electrical stimulation applied) and the "control" step (without cyclic electrical stimulation). The sequence of "experimental/control" steps offered to participants changed on a rota basis.

6. The device-based method of cyclic electrical stimulation was implemented with the aid of a stimulating cyclic electric stimulator CES-1 manufactured by SpecTechPro company (Kharkiv, head of the project I.A. Rybachenko, Ukrainian utility patent No. 85142 of 11.11.2013, conformity to the safety standard for electrical stimulators of nerves and muscles DSTU ISO/IEC 17025:2006). The device was fixed on the left forearm from the outside, amperage/voltage of the current and stimulus frequency were selected individually until the effect was perceivable but caused no pain. The device allows variability within 25 amperage modes (ranging from 0.6V and 0.72 mA to 3.62V and 3.74 mA with substitute load of 1000 Ohm) and 5 impulse action frequency modes (ranging from 1 impulse every 3 seconds to 1 impulse every 15 seconds). During the experimental step electrodermal stimulation was applied for the whole period of 25 minutes with the selected frequency and amperage. During the procedure the participants occasionally decreased the amperage and frequency of electrodermal stimulation.

The study lasted on average 1.5 hours for each participant. The experimental design included instructing the participant, the stage of assessment of the initial state using a questionnaire, HRV and reaction time data, the first monotonous activity procedure with/without electrical stimulation (depending on the sequence), interim assessment using a questionnaire, HRV and reaction time data, the second monotonous activity procedure with/without electrical stimulation (depending on the sequence) and final assessment using a questionnaire, HRV and reaction time data. Monotonous activity procedures were carried out with continuous EEG recording. The obtained data were analyzed using MS Excel 2010 and StatSoft STATISTICA 7.0. The study program was approved by the ethics committee of the

School of Psychology at V.N. Karazin Kharkiv National University.

RESEARCH RESULTS

Subjective scaling results

Comparison of the participants' condition self-assessment results henceforward was carried out using Student's t-test for dependent samples (slippage test) between: 1) initial state (IS) and the state after a monotonous activity procedure (MA); 2) the state after a MA procedure and the state after a monotonous activity procedure with electric stimulation (MAES); 3) IS and the state following the MAES. All the three cases demonstrated significant differences, namely: 1) the monotony sensation is significantly more pronounced after the MA procedure (mean M=28.4) compared to IS (M=12.5; p<0.001); 2) the monotony sensation is significantly less pronounced after the MAES procedure (M=18.0) compared to the post-MA data (M=28.4; p<0.001); 3) the monotony sensation is significantly less pronounced in IS (M=12.5) than after the MAES procedure (M=18.0; p<0.001) – see the Figure.

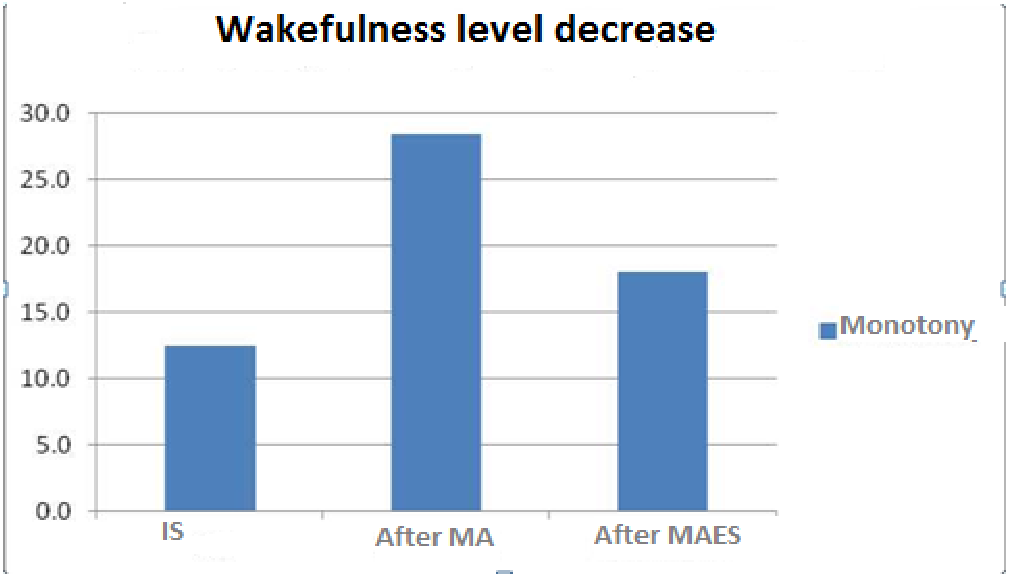

Figure.Wakefulness level decrease in the initial state, after the MA procedure and after the MAES procedure

Commenting on the diagram, one should note that even in the initial state, not all study subjects are in the state of absolute wakefulness, as they might have natural signs of fatigue or sleep deprivation.

A detailed analysis of all questionnaire data shows that significant differences at the MA/MAES stages are found for all the 12 monotony symptoms, although there are no differences between the IS and MA stages in terms of "decreased pulse and breathing sensation", while there are no differences between the IS and MAES stages in terms of "lack of alertness", "lack of mental agility", and "decreased pulse and breathing sensation". This means that the electric stimulation method eliminates monotony with respect to the latter three criteria, as it restores a participant's initial state observed before the participant's exposure to a monotonous perceptual activity. A most effective reduction of monotony with application of electrical stimulation is observed for the criteria linked to decreased mental agility, eyes closing, numbness, "shutoff", lack of readiness to act, drowsiness, as significant differences were obtained for these 6 criteria not only within the p<0.050 interval, but also with p<0.001.

EEG analysis results

There are no differences between the indices of principal EEG activity rhythms observed between the MA and MAES stages.

HRV analysis results

There are no differences in the heart rates and heart rate variability indicators observed after the comparison of data collected after the MA and MAES procedures, which suggests the absence of any effect of cyclic electric stimulation of the forearm on the cardiac activity. Simultaneously, there are significant differences between the HRV parameters observed for IS when compared to both the after-MA and after-MAES states (see the Table).

Table

Differences between the IS parameters of cardiac activity and after-MA and after-MAES states

HRV parameters	**IS**	**After MA**	**After MAES**
Heart rate	81.6	73.0 ($p<0.001$)	73.4 ($p<0.001$)
SDNN	47.4	57.5 ($p<0.050$)	54.6 ($p<0.050$)
pNN50%	12.2	19.7 ($p<0.050$)	17.7 ($p<0.050$)
SI	169.6	93.5 ($p<0.001$)	98.5 ($p<0.050$)

Any changes in the cardiac activity following the procedures causing monotony are indicative of the body switching to the relaxed mode, autonomous control, and a decreased stress index for the regulatory systems, that is restorative and trophic processes.

Reaction time analysis results

There are no significant changes in the reaction times of the study subjects between the IS, MA, and MAES stages.

Effects of independent factors

In order to analyze the role of independent variables (gender, age, exposure sequence, current amperage and frequency, test time, previous night's sleep duration, initial decrease in wakefulness level) that can disguise differences in the principal studied indicators (EEG, HRV, and reaction time), we subdivided the general sample into subpopulations differentiated according to the listed criteria and compared the MA and MAES data within those subpopulations. Subjective scaling data were not analyzed taking into account independent factors due to the previously established significant differences.

The exposure sequence factor. Subdivision of the sample into two subpopulations, the one where the MAES experiment was held first (15 subjects) and the one where exposure to MA procedure took place first (16 subjects) allowed establishing a lower rate of heart rate variability with electric stimulation applied than without it for the subpopulation where electric stimulation came first. It was manifest in a lower SDNN (standard deviation of RR intervals), TP (total power of the neurohumoral regulation range), and a higher SI (stress index of the regulatory systems) at the MAES stage than at the stage when monotonous activity was not accompanied by electrical stimulation. This suggests that in case if the experiment starts with electrical stimulation, the participants develop a mild stress level causing a lower HRV rate. If exposure to electrical stimulation is preceded by a period of monotonous activity without electrical stimulation, the said effect does not develop. At the same time, the stress that develops does not push the HRV indices beyond the norm [1], which allows considering it as a positive, invigorating eustress rather than a distress (in H.Selye's terms) [9].

The age factor. Subdivision of the sample into two subpopulations – the younger subjects (below 35, 19 subjects) and the older subjects (over 35, 12 subjects) demonstrated that the older subpopulation had a slight (within normal limits) decrease in the HRV indices rates (SDNN, TP, and LF) at the after-MAES stage in comparison with the after-MA stage. This means that electric stimulation has a stronger stimulating effect on the older age group involving the level of central (hypothalamic and pituitary regulation).

The gender factor. The female subpopulation demonstrated a lower beta 2-activity index at the initial stage of the MAES procedure (beta 2-activity index 6.08) in comparison with the initial MA stage (beta 2-activity index 6.97, p=0.005), as well as higher theta- and delta 2-activity at the principal MAES stage (theta-activity index 14.8, delta 2-activity index 13.4) in comparison with the principal MA stage (theta activity index 14.1, delta 2-activity index 12.5, p=0.039). There are no differences observed in EEG, HRV, or reaction time between the MA and MAES stages in the male subpopulation. Thus, females tend to be more responsive to electric stimulation, but this response is opposite to the anticipated reaction – first there is a decrease in the fast beta 2-rhythm associated with attention focusing, which is then followed by an increase in the slow theta- and delta-rhythms associated with deactivation and drowsiness.

The amperage factor. Subdivision of the sample into the subpopulation exposed to minimal current amperage (18 subjects, 0.6V and 0.72 mA) and the population exposed to higher amperage levels (13 subjects, ranging from 0.89V and 0.83 A to 1.77V and 1.77mA) showed that in the lower amperage subgroup there is a decrease in the beta 2-activity at the initial MAES stage (beta 2-rhythm index 5.7) in comparison with the initial MA stage (beta 2-rhythm index 6.4, p=0.020). This can be explained by the fact that people experiencing more discomfort during electric stimulation (and therefore selecting a minimal stimulation mode) tend to shift their focus between the sensations caused by electric stimulation and the slides.

The current frequency factor. The electric stimulation frequency factor has an effect identical to that of the amperage factor on the group selecting a lower frequency (14 subjects, once every 10 and 15 seconds), that is experiencing more discomfort than the group selecting stimulation at higher frequency rates (17 subjects, once every 3, 5, and 7 seconds). The group with the lower frequency of electric stimulation demonstrated a decrease in the beta 2-activity at the principal MAES stage (beta 2-activity index 5.9) in comparison with the principal MA stage (beta 2-activity index 6.8; p=0.023).

The test time factor. In order to take into account the circadian rhythms, the sample was subdivided into three subpopulations: subjects undergoing the test in the morning (9 subjects, from 8.30 to 11.00), those taking the test at daytime (16 subjects, from 11.00 to 17.00) and those undergoing the test in the evening (6 subjects, from 17.00 to 19.30). During the daytime testing there was a slight decrease in the reaction time after the MAES procedure (reaction time 424.3 ms) in comparison with the after-MA period (reaction time 397.8 ms, p=0.027).

The factor of previous night's sleep duration. There were no significant differences found between the subpopulation of subjects that had had a sufficiently long sleep period (7 hours and more, 23 subjects) and those who had slept less (less than 7 hours, 8 subjects).

The factor of initial rate of decrease in wakefulness. Subdivision of the sample into a group with the initially lower level of wakefulness (15 subjects, monotony level above average – more than 12 points) and a group with the initially higher level of wakefulness (16 subjects, monotony level below average – less than 12 points) demonstrated that in the group with a higher initial level of monotony HRV decreases after MAES (mean SDNN=49.4) in comparison with the after-MA stage (mean SDNN=58.1; p=0.010). This means that for the participants who initially have a lower level of wakefulness electrical stimulation causes more intensive activation of the central level of regulation of cardiac activity which, nevertheless, remains within normal limits [1].

DISCUSSION OF RESULTS

The results of subjective scaling positively demonstrate that electrical stimulation significantly (over 1.5 times) decreases reportable signs of wakefulness level decrease in the participants. However, the monotony sensation remains, which is demonstrated by incompleteness of its reduction that never reaches initial rates in any of the applied criteria, except “lack of alertness’, “lack of mental agility”, as well as “decreased pulse and breathing sensation”. This means that the electrical stimulation method is especially effective for the purposes of restoring the required alertness and mental agility levels, as well as the normal tonic state of the pulse and breathing.

The obtained effect of decreased pulse and increased HRV after both MA and MAES procedures is non-random and presumably conserved, as uniform and monotonous environment during the primary Hominidae evolution period suggested hazard-free surroundings and therefore allowed using the circumstances to save energy. According to Borbely [quoted in 10, p. 260], the “sleep/wakefulness” cycle is a more flexible mechanism than the rigidly programmed circadian rhythm and allows adapting the rest/activity periods to the changing environment and the body’s needs. According to I.P. Pavlov’s description of the state, “These surroundings are permanently monotonous for dogs, and since there are no variations in the surroundings for them, no activity is needed, there is no point in plain sitting, sleep will do at least some good. It is an absolutely natural stimulant of the inhibitory process [quoted in 6, p. 205]. Relying on the assumption of the deep evolutionary “rootedness” of this reaction to a monotonous environment, it becomes clear why it is so hard to overcome it in the dramatically different technology-based environment of today, when the instinct is “falsely activated” by a stimulant from the environment that appears similar but is essentially different.

Analysis of the sequence factor demonstrated that application of electrical stimulation immediately after the beginning of monotonous activity causes a mild physiological stress. If electrical stimulation occurs a half-hour after exposure to monotonous activity, such a physiological stress does not develop, as, probably, the psychological stress caused by monotonous activity itself is quite unpleasant, and the invigorating effect of electrodermal stimulation is not perceived as stressful by the body.

Analysis of some independent factors shows that people experiencing more pronounced discomfort during electrical stimulation (participants selecting milder stimulation modes, female subjects having more bodily fears than men) have lower beta 2-rhythm rates, which can be explained by attention refocusing between the target stimulus (the slide show) and the stimulating one (electrical stimulation). This effect can be linked to the subject being unaccustomed to electrical stimulation and is likely to reduce at repeated applications of the device. This issue requires additional tests.

The absence of any pronounced changes in EEG, HRV, and reaction time can be explained by the complexity and heterogeneity of activities of the brain’s modulating system [4], whose multidirectional effects are impossible to clearly detect within the stipulated period of monotonous activity. Nevertheless, at the subjective level 90% of study participants had a higher wakefulness level and a reduced monotony state.

CONCLUSION

An experimental testing of the effects of cyclic electrical stimulation on maintenance of the conscious state and prevention of sleepiness paroxysms has proven its effectiveness which is manifest in a significantly higher level of perceived wakefulness and reduced signs of falling asleep in participants in the experiment.

One should note that assessment of the quality of any psychophysiological method requires not only demonstration of its empirical effectiveness, but also an explanation of its mechanism. We can explain the effectiveness of the electrical stimulation method for prevention of advanced monotony stages using the following the principle. Maintenance of a wakefulness level requires sufficient stimulation (internal if not external) received by the brain. It is one of the self-regulation mechanisms of the body – with a reduced rate of external stimulation a man starts moving in order to intensify the ascendant sensory input going from the functioning muscles to the brain [9]. Muscular relaxation, blocked muscular activity within a monotonous external context results in the accelerated decrease of wakefulness level. Cyclic electrical stimulation applied to the skin, muscles, and nerves of the arm adjustable by the user of the TsES-1 device during the activity, creates additional brain stimulation, preventing the wakefulness level from dropping to the point of occurrence of sleep paroxysms.

This effect makes the method stand out to advantage from among other modern devices developed to fight monotony. While almost every device registers the onset of sleep post factum, utilization of the TsES-1 device allows achieving wakefulness without short-term lapses of consciousness, which is especially important for such target situations as driving a vehicle, staying on alert and controlling work.

Additional favorable effects of applying the TsES-1 device include maintenance of a notably high level of alertness and mental agility and allow considering the device as an effective means of enhancing working capacity during exposure to lasting mental workload. This field requires further research.

In addition, since electrodermal stimulation is used in applied psychophysiology for development of stress resistance and extinction of the defensive reflex during the effects of annoyers (as part of neurofeedback therapy), one could expect a non-specific effect of cyclic electrical stimulation manifest in the general growth of stress resistance of the subjects using the method to counteract monotony.

SUMMARY

RESEARCH of a METHOD of CYCLIC ELECTRICAL INFLUENCE FOR PREVENTION PAROCSISMS of a SLEEPY CONDITION in CONDITIONS of MONOTONOUS ACTIVITY Luzenko E.L. Ukraine, Kharkov, Kharkov national university of a name V. N. Karazin psydilab@gmail.com

The problem of uncontrolled falling asleep under monotonous conditions on transport, on alert duty, at automatized work and other similar situations is still unsolved and very actual. The paper presents results of an experiment which was aimed to assess the effectiveness of cyclical electrical stimulation method for conscious state maintenance and sleeping paroxysms' condition counteraction. The method is realized by cyclical electric stimulator CES-1 developed by SpecTechPro company (project derector I. A. Rybachenko). With the sample of 31 persons was carried out an experimental design which included monotony state modeling with electrical stimulation and without it, assessment of participants' subjective state, EEG, HRV and time reaction analysis. The results of subjective scaling reliably demonstrate that electrical stimulation significantly (half as much again) reduces participants' conscious signs of wakefulness level decline. Marked changes in the EEG, heart rate variability and reaction time were not fond. Key words: electrical influence, monotony, electrical research of a brain, change of an intimate rhythm, subjective scales.

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