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Dynamics of cognitive and neurophysiological functions of a person in the simulation of weightlessness in terrestrial conditions

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Introduction. The authors have conducted a study of the influence of the conditions of 21-day antiorthostatic hypokinesia (AOSH) on the dynamics of neurophysiological reactions and cognitive functions of a person on the basis of Institute of Biomedical Problems, RAS, with the participation of six healthy male volunteers aged 24 to 40 years (30.7±5.4) who were in bed with hypokinesia in an antiorthostatic position with an angle of inclination –6° relative to the horizon.

The study aims to determine the dynamics of neurophysiological reactions and cognitive functions of a person during a 21–day AOSH (–6°).

Materials and methods. The researchers analyzed the dynamics of cognitive functions based on the results of performing complex dynamic tasks with elements of uncertainty from the CleverBalls software test block. The authors determined the dynamics of neurophysiological reactions by the relative dynamics index (RDI) of the relative power value (RPV) of all the studied ranges of the EEG spectrum. The experts carried out measurements of all indicators before the start of the study (Background), on the 3rd (1st session), 10th (2nd session), 17th (3rd session) and 21st (4th session) days, as well as 3 days after the end of the experiment — aftereffect (After).

Results. Scientists have found an increase in inhibitory processes in the brain as a result of solving complex dynamic tasks with elements of uncertainty in the acute period (3 days) and in the aftereffect. After the acute period and before the end of the experiment, they observed the restoration of brain functions to the background level. An increase in the performance of complex dynamic tasks with elements of uncertainty (according to the indicators "Percentage of correct choice" and "Average harmonic click time") was observed from ten days to the aftereffect inclusive, which indicated, at least, the absence of a decrease in cognitive functions during the 21-day AOSH.

Conclusion. *At the end of the experiment, the authors noted a less pronounced increase in Delta and Theta activity than in the acute period, with a simultaneous decrease in Alpha and Beta activity, but at the same time, they did not observe a decrease in the success of cognitive tests.*

Ethics. The program of the experiment was approved at the section of the Scientific Council and approved by the Commission on Biomedical Ethics at the Institute of Biomedical Problems, RAS (Protocol No. 599 of 06.10.2021).

Keywords: *antiorthostatic hypokinesia; complex dynamic tasks; uncertainty; electroencephalography*

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Contribution:
Polyanichenko A.A. — research concept and design, data collection, analysis and interpretation, article writing;
Shlyavtseva D.V. — data collection, analysis and interpretation;
Kotrovskaya T.I. — data analysis and interpretation, article writing, article editing;
Golubev V.G. — development of a test block for "CleverBalls";
Smolyakov D.G. — developer of the software "CleverBalls".

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Introduction. Modeling of space flight factors is an important condition for improving medical and biological support and support of professional activities of astronauts [1, 2].

The method of modeling in terrestrial conditions of human stay in weightlessness, as well as on planets with reduced gravity is antiorthostatic hypokinesia (AOSH), which consists in the fact that volunteers are in bed hypokinesia in an antiorthostatic position with an angle of inclination from 4° to 12° relative to the horizon [3, 5, 6]. The position of the body studied in AOSH leads to a redistribution of the body's fluid media in the cranial direction, which activates adaptive mechanisms, in particular, of the central and peripheral nervous system [4, 7, 8]. In conditions of redistribution of body fluids in the cranial direction, fluid transudation from capillaries into the head tissue increases [9]. Cerebral disorders lead to deterioration of cognitive functions [10, 11], and, consequently, to maladaptation.

The study of the combined effect of AOSH (–6°) and elevated CO_2 content on the brain for 30 days showed significant changes in cerebral connectivity between the vestibular, visual, somatosensory and motor areas of the brain, which were largely associated with changes in sensorimotor activity [12].

The study aims to determine the dynamics of neurophysiological reactions and cognitive functions of a person during a 21–day AOSH (–6°), when performing complex dynamic tasks with elements of uncertainty.

Materials and methods. On the basis of the Institute of Biomedical Problems, RAS, scientists conducted an experimental study of the effect on human neurophysiological reactions and on the success of complex dynamic tasks of the conditions of 21–day AOSH. Six healthy male volunteers aged 24 to 40 years (30.7±5.4) were in bed hypokinesia for 21 days in an anti-orthostatic position with an angle of inclination of –6° relative to the horizon.

The researchers determined the dynamics of cognitive functions by analyzing the results of complex dynamic tasks with elements of uncertainty from the CleverBalls test block developed by Golubev V.G. With the help of this test block, it is possible to determine the volume of short-term memory, the latent period of a simple motor reaction, the latent period of visual-motor reaction, productivity (speed) of operator activity, accuracy and reliability of operator activity, an error in the recognition of visual images.

Three tasks with elements of uncertainty from the set of cognitive tests "CleverBalls" were presented before the start of the study (background), on the 3rd (1st session), 10th (2nd session), 17th (3rd session) and 21st (4th session) days, as well as for 3 days after the end of the experiment — aftereffect (After):

1. In the "NEO" task, white numbers from 1 to 9 on a black background were presented on the computer monitor, which moved randomly at a speed of 125 ms. If there were no digits from 1 to 5, the subject had to press the "←4" key, if there were no digits from 6 to 9 — the "6→" key. In case of a pressing error, the block of numbers was highlighted in green, after which it was necessary to press the correct key. If all the numbers are present, you had to press the "A(F)" key, if you pressed an error, "0" appeared on the screen on a green background. There was no time limit for the answer. To continue the training, the subject had to press the key corresponding to the correct answer. If the answer was correct, a green exclamation mark appeared on the screen; after it disappeared, the training continued.

2. In the Scout test, gray balls with the letters "E" and "F" in black and red appeared on a computer monitor on a blue background. The balls were divided into groups according to the color of the letters. The subject had to indicate the color of the group (black — by pressing the "Z" key or red — "1End"), in which there was a letter that did not coincide with the rest of this color group; in case of mismatch of letters in color in both groups, press "2↓". After each correct answer, the number of balls ("interference") gradually increased, and if a mistake was made, it decreased to the previous level. The maximum number of balls was 35 pieces. There was no time limit for the answer. The speed of movement of the balls with letters was 250 ms.

3. In the "zero" task, an array of (60) yellow balls was presented on a computer monitor on a black background, among which there could be black ones (from 0 to 5). The test subject had to determine the presence of hidden black balls by pressing the "1 End" key, or their absence by pressing "Z". With the correct answer, hidden balls (or the whole array) they changed the color to white, if an error occurred, the hidden balls (or the entire array) were highlighted with red frames. To proceed to the next stage, it was necessary to press the key on the digital block, which corresponds to the number of hidden balls. There was no time limit for the answer. The speed of movement of the balls during one stage was different — from 170 to 430 ms.

The parameters issued by the Clever Balls software for each task were: the number of complete stages completed; Arithmetic mean pressing time (ms); Harmonic mean pressing time (ms); Shortest stage Execution time (ms); Average stage Execution time (ms); Longest stage Execution time (ms); Percentage of correct selection; Percentage of Erroneous pressing time (ms); Average pressing time (ms); Maximum pressing time (ms).

For the secondary analysis, an indicator of the average harmonic click time was selected from all the different time parameters, since the emissions of a long reaction time were leveled, and the time required for the subject to make a decision and react using the mouse or pressing the keyboard key after updating the image of stimuli was calculated.

The authors evaluated the dynamics of the functional state of the brain using the EEG registration method before and after performing three tasks with elements of uncertainty from the battery of cognitive tests of the Clever balls software before the start of the study (background), at 3 (1st session), 10 (2nd session), 17 (3rd session) and 21 (4th session) per day, as well as three days after the end of the experiment (after).

The authors recorded EEG from 19 standard leads according to the international scheme of 10–20% [13], then calculated the relative dynamics index (RDI) of the relative power value (RPV) of all the studied ranges of the EEG spectrum. RDI was calculated as the ratio of EGG parameters after performing cognitive tests to EGG indicators obtained before solving problems.

The experts generalized and analyzed the data obtained using nonparametric statistics using the STATISTICA 10 computer program. To check the statistical significance of the differences, the paired Wilcoxon T-test was used.

Results. A cumulative analysis of the data obtained for each Clever Balls software test showed that under experimental conditions the most informative indicators were "Average harmonic click time" ***(Fig. 1)*** and "Percentage of correct choice" ***(Fig. 2)***.

The increase in the indicator "Average harmonic click time" was revealed only when performing the task — "NEO" in sections 2, 3, 4, 43%, 51.6%, 42.6%, respectively ***(Fig. 1)*** relative to the background.

The indicator "Percentage of correct choice" increased relative to the background when solving the problem:

- "NEO" ***(Fig. 2A)*** in sessions 2, 3, 4 and in the Field by 36.7%, 39%, 37% and 27%, respectively;
- "Scout" ***(Fig. 2B)*** in sessions 1, 2, 3, 4 and After on 13%, 18,7%, 22,6%, 31%, 47% accordingly;
- "Zero" ***(Fig. 2C)*** in sessions 2, 4 and After by 31%, 41.5% and 40.2%, respectively.

Thus, there was an increase in the effectiveness of performing complex dynamic tasks with elements of uncertainty (according to the indicators "Percentage of correct choice" and "Average harmonic click time"), which indicated successful training in performing such tasks and,

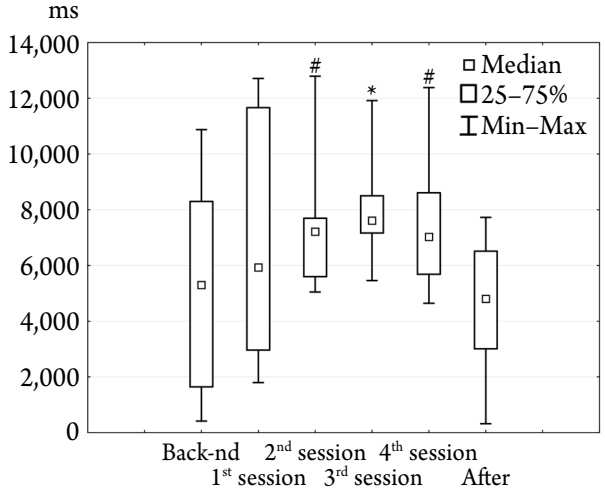

Figure 1. Harmonic average click time for the "NEO" test.
Note: * — $p \leq 0.05$; # — trend ($p \leq 0.1$).

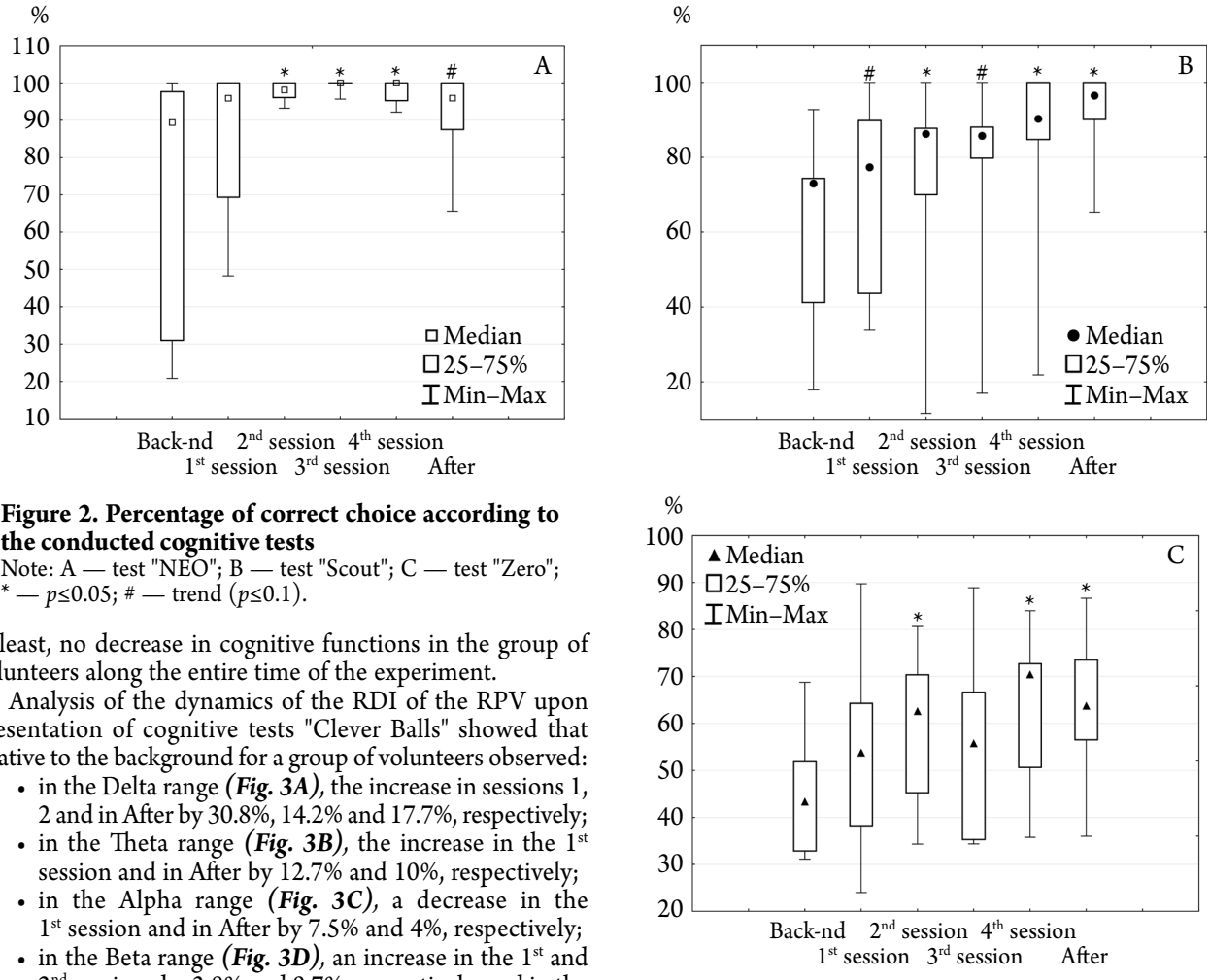

Figure 2. Percentage of correct choice according to the conducted cognitive tests
Note: A — test "NEO"; B — test "Scout"; C — test "Zero"; * — $p \leq 0.05$; # — trend ($p \leq 0.1$).

at least, no decrease in cognitive functions in the group of volunteers along the entire time of the experiment.

Analysis of the dynamics of the RDI of the RPV upon presentation of cognitive tests "Clever Balls" showed that relative to the background for a group of volunteers observed:

- in the Delta range ***(Fig. 3A)***, the increase in sessions 1, 2 and in After by 30.8%, 14.2% and 17.7%, respectively;
- in the Theta range ***(Fig. 3B)***, the increase in the 1st session and in After by 12.7% and 10%, respectively;
- in the Alpha range ***(Fig. 3C)***, a decrease in the 1st session and in After by 7.5% and 4%, respectively;
- in the Beta range ***(Fig. 3D)***, an increase in the 1st and 2nd sessions by 3.8% and 0.7%, respectively, and in the 4th session — a decrease by 7.5%.

Thus, in the acute phase (session 1) of the AOSH experiment, the authors noted a complex of changes in the ranges of RDI RPV EEG, significantly smaller shifts were found in the aftereffect and their practical absence in the rest of the study. In session 1, slow-wave (Delta-, Theta-) activity increased, Alpha-decreased, and Beta-activity increased slightly, at the level of statistical error. Such a set of EEG characteristics, recorded in a state of calm wakefulness with closed eyes, indicates an increase in inhibitory processes in the brain as a result of performing a battery of cognitive tests.

Discussion. The results obtained indicate that the conditions of a 21-day AOSH do not worsen cognitive functions in a small sample of subjects, both during the study itself and after it. In the acute phase, as a result of the volunteers performing a block of complex dynamic tasks, they developed inhibition processes in the brain, then no such changes were detected during the entire study; at the end, less pronounced inhibitory processes were observed than in the acute phase.

The results of studies of the effect of AOSH on cognitive functions have many discrepancies due to the variety of cognitive test batteries used, the conditions and duration of experiments, the testing time during the day, as well as the sample size [14].

Similar results obtained in this work are described by a number of authors who noted the absence of a decrease in cognitive functions in groups of subjects even with a longer duration of AOSN and the complexity of spatial tasks compared to the present study [15–18], although when performing a double task in conditions with prolonged AOSN, researchers revealed a decrease in accuracy, but an increase in the speed of its solution [19], and, conversely, a moderate slowdown in the performance of sensorimotor tasks with constant accuracy was observed [4].

When studying the features of the subjects' EEG under conditions of 30-day AOSH (–8°), the authors revealed an increase in: EEG instability, the specific gravity of polymorphic slow activity, synchronization by alpha rhythm, which were correlates of a decrease in the level of brain wakefulness [20]. In a study of the effects of AOSH without cognitive load, it was noted that the spectral power of the EEG during the YEAR was significantly reduced in the delta, theta, alpha and beta frequency ranges. The experts observed these changes shortly after the start of AOSH (after 24 hours), they did not change throughout the experiment and returned to the initial level after its completion [3].

Unlike a separate study of cognitive functions and the functional state of the brain under conditions of antiorthostatic hypokinesia, in the study, EEG registration was carried out against the background of solving complex dynamic tasks with elements of uncertainty from a battery of cognitive tests. The maximum was the change in the ratio of the level of the RPV EEG ranges in the acute phase of the AOSH experiment to the complex of these parameters in the background.

Limitations. The study is limited to a small sample of subjects.

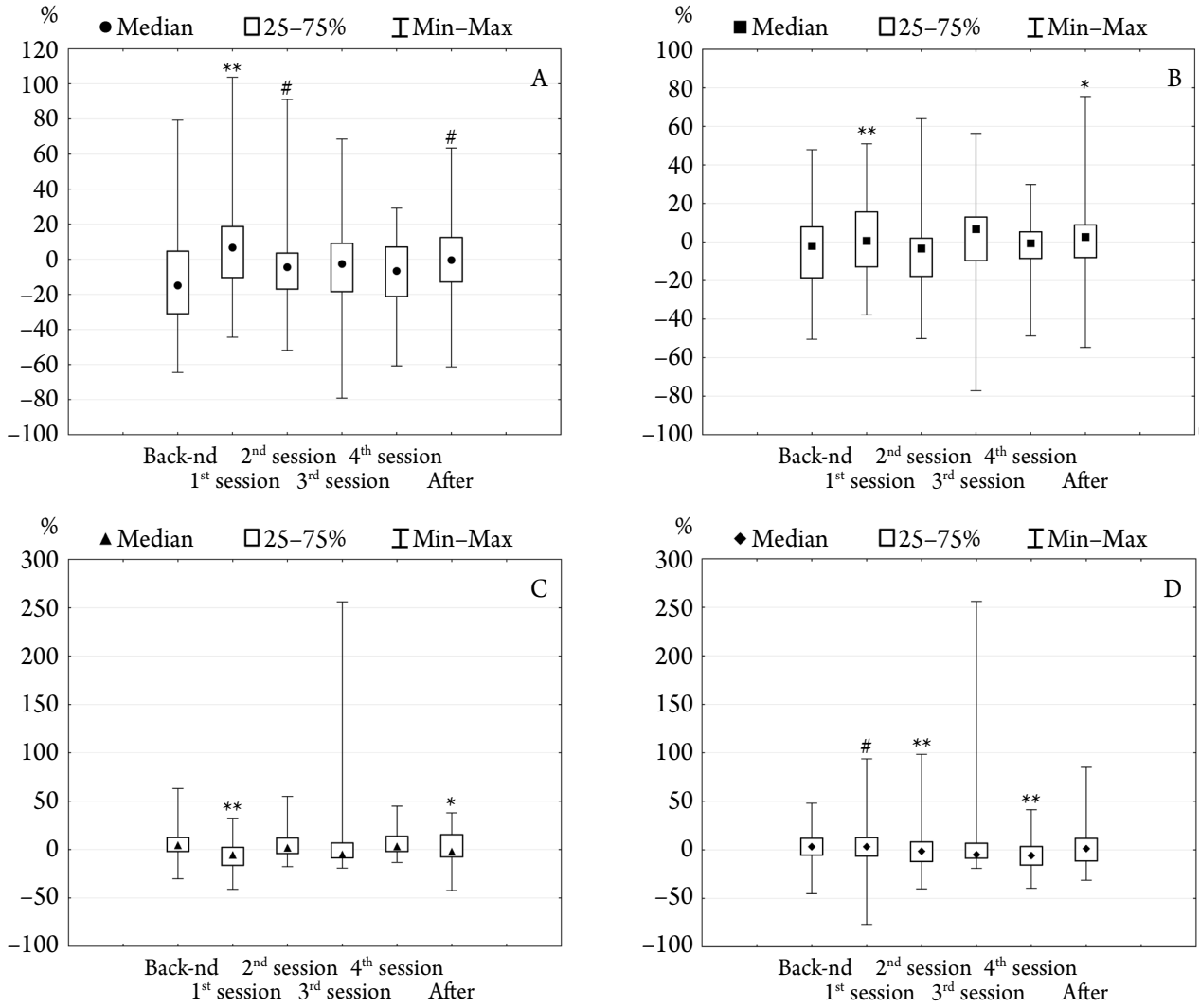

Figure 3. Relative dynamics index of all the studied ranges
Note: A — RPV of the Delta-range, B — RPV of the Theta-range, C — RPV of the Alpha-range; D — RPV of the Beta-range; * — $p \leq 0.05$; ** — $p \leq 0.01$; # — trend ($p \leq 0.1$).

Conclusion. *The study of the dynamics of neurophysiological reactions and cognitive functions of a person during a 21-day AOSN (–6°) revealed the presence of inhibitory processes in the brain as a result of solving complex dynamic tasks with elements of uncertainty in the acute period, while the improvement of cognitive functions was observed by the authors according to the indicator "Percentage of correct choice" only for the Scout test. Next, we observed the restoration of brain functions to the background level and an improvement in cognitive activity in accordance with the characteristics of the correct answers and the time of their choice. At the end of the experiment, the researchers observed a less pronounced increase in Delta and Theta activity than in the acute period, with a simultaneous decrease in Alpha and Beta activity, but at the same time, they did not observe a decrease in the success of cognitive tests.*

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