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16. Abstract This article discusses research on the phenomenology for the reactions of the vestibular system and the function of spatial perception in astronauts. Examinations were given both pre- and post-flight.

Each astronaut was different but space flight definitely caused changes in the activity of the vestibular apparatus and spatial functions.

Details of the pre/post flight examinations and some conclusions are presented in the 15 pages.

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RESULTS OF STUDYING THE VESTIBULAR APPARATUS AND THE SPATIAL PERCEPTION FUNCTION OF COSMONAUTS (PRE- and POST-FLIGHT EXAMINATIONS)

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Analysis of the medical support for manned space flights both in our country and in the United States has shown that vestibular-autonomic disorders and disorders in spatial perception developed in many cosmonauts. These disorders were the most pronounced in the initial adaptation period for weightlessness, as well as in the initial period of readaptation to terrestrial conditions. /1*

There have been many discussions and hypotheses on the genesis of the vestibulo-autonomic symptom complex and the illusion of spatial position in outer space. The approaches to solving this problem are presented in the report of Dr. Matsnev. Despite the abundance of hypotheses, the majority of researchers attribute primary importance to the unusual functioning of the vestibular apparatus and the systems interacting with it [1-15].

Studies on the human vestibular function under weightlessness conditions have been individual. They have been conducted in the USSR and the United States during various space expeditions (Gemini, Skylab, Vostok and Soyuz). The findings were contradictory and made it possible to reveal individual reactions that indicate the possible change in the function of the vestibular apparatus.

It goes without saying that studies of the sensory systems and their regulation in the actual space flight have the greatest importance

*Numbers in margin indicate pagination in original foreign text.

in clarifying the neurophysiological mechanisms for the development of motion sickness. At the same time, ground studies that can be conducted before and after the flight, to a certain degree permit pinpointing of the possible mechanisms for the observed shifts. /2

The task of this research was to study the phenomenology for the reactions of the vestibular system and the function of spatial perception according to the data of pre- and post-flight examination.

Volume and Methods of Study

An examination was made of 24 cosmonauts who had made flights on the Soyuz type craft and the Soyuz-Salyut orbital complex. Six of them were examined twice. Studies were made during 10 short flights (4-7-10 days) and during 5 long flights (from 30 to 175 days) (table 1).

All the cosmonauts passed expert clinical and physiological examination. They were pronounced healthy, including for the condition of the ORL (otorhinolaryngological) organs.

The following techniques were used to evaluate the condition of the vestibular apparatus and the function of spatial perception.

1. The otolithic reflex was studied according to the amount of eye counterrevolution reaction. A visual sequential pattern was used with transition from the vertical to the horizontal position to the right and left side. This was a modification of the indirect otolithometry method according to Fischer and Fluur [16,17].

The function of the semicircular canals was studied according to the value of the thresholds of sensitivity to change in angular velocity (according to nystagmus and the sensory component).

3. The spatial coordinate perception function was studied with the portable "Vertikal'" instrument [18] in the sitting position, and /4
in a horizontal position on the right and left sides. In the first three types of studies the symmetry of the reactions was determined in addition to their amounts.

TABLE 1. CONTINGENT OF SUBJECTS /3

No. in order	Space program	Crew members	Duration of flight	
			short	long
1.	Soyuz-17-Salyut 4	CC-FE	-	30
2.	Soyuz-19-Apollo	CC*FE*	7	-
3.	Soyuz-21-Salyut 5	CC*-FE	-	30
4.	Soyuz-22	CC*-FE	7	-
5.	Soyuz-24-Salyut-5	CC*-FE	19	-
6.	Soyuz-26-Salyut-6	CC-FE*	-	96
7.	Soyuz-27-Salyut-6	CC-FE	7	-
8.	Soyuz-28-Salyut-6	CC*-FE	7	-
9.	Soyuz-29-Salyut-6	CC*-FE	-	140
10.	Soyuz-30-Salyut-6	CC*-FE	7	-
11.	Soyuz-31-Salyut-6	CC**-RC	7	-
12.	Soyuz-32-Salyut-6	CC-FE*	-	175
13.	Soyuz-36-Salyut-6	CC**-RC	7	-
14.	Soyuz-T-2-Salyut-6	CC-FE	4	-
15.	Soyuz-37-Salyut-6	CC**-RC	7	-
	Total	30	10	

Designations: CC--crew commander
RC--research cosmonaut
FE--flight engineer
*--second flight
**--third flight

4. A study was made of the features of interaction between the otolithic organ and the semicircular canals according to nystagmus and the sensory component using a modified "otolithic reaction" (OR) test of Voyachek. It used a dosed effect of angular accelerations with subsequent postural change that is dosed for velocity and direction. During the test, the pronounced nature of the autonomic reactions (AR) was assessed according to K. L. Khilov's classification and the data of recording the pulse rate, respiration, arterial pressure and electrocardiogram (PR, RR, AP and EKG).

5. A special questionnaire was used to record reactions during the space flight.

The otolithic reflex, thresholds for angular accelerations and the spatial coordinate perception function were studied from three to six times with a background examination (30-45 days before the flight), and an analogous number of times on the 0, or 1-2, 4-5 days, during long expeditions 8-9 days, and further 1 month after the flight.

The volume and periods of study are presented in table 2.

All methods were used to make a preliminary determination of the reaction standards in examining 112 healthy males in age from 25 to 40 (table 3).

Studies of the otolithic reflex and the accuracy of spatial coordinate perception were conducted in dynamics on 100 people with different pathology of the vestibular analyzer: Meniere's disease (35 people), cochleovestibulopathy of vascular genesis (45 people) and limited labyrinthitis (20 people).

Data of Preflight Examination /7

Indicators for the intensity of the otolithic reflex in 20 cosmonauts, including in 2 people in repeated flights, were within the limits of fluctuations of the physiological standard. They were symmetrical, or the assymetry did not exceed the physiological spread. The data of the following cosmonauts were an exception: crew commander (CC) of the craft Soyuz-22 and Soyuz-31 (in both studies they had low indicators of this reflex (1-2°)), crew commander of the Soyuz-26 craft and the flight engineer of the Soyuz-32 craft had reflex asymmetry (I>D) that exceeded the physiological spread and was 8° and 9°.

The original amounts for the sensitivity thresholds of the cupula receptors to a change in angular velocity in all cosmonauts except the CC (crew commander) of the first expedition of the Soyuz-Salyut-6 orbital complex, were in limits of the physiological fluctuations of the given indicator. They corresponded to $2°/s^2$-$6°/s^2$. The threshold amounts were practically symmetrical. The sensitivity threshold of the semicircular canals of the the CC of this expedition was increased to $11°/s^2$ and was asymmetrical (Δ=6°).

The indicators for the accuracy of spatial coordinate perception in the background examinations of 21 cosmonauts, including 5 in repeated flights, were in the limits of fluctuations in the physiological standard. There was either no difference in the errors in spatial coordinate perception in the lateral positions, or the difference was

TABLE 2. VOLUME AND PERIOD OF STUDIES

No. in order	Studied functions	Number		Days		Recorded parameters
		of examined	of studies	before flight	after flight	
1.	Otolithic reflex	22*	348	30 or 45	0 or 1 2,4-5 8-9, further in 1 month	angular degrees of eye counterrotation, symmetry of indicators in position on right and left side
2.	Accuracy of perception of spatial coordinates	24**	360	30 or 45	0 or 1-2, 4-5, 8-9, further in 1 month	Error in degrees, sitting and in position on right and left side, symmetry of reactions
3.	Threshold sensitivity of semicircular canals	24**	92	3 or 5	2 or 4-5,8-9, further in 1 month	Amount of acceleration (ENG and illusion). Symmetry of reaction during right-left rotation
4.	Interaction of semicircular canals and otolithic apparatus	24**	92	3 or 5	2 or 4-5,8-9, further in 1 month	ENG, illusion of counter-revolutions, AR
	Total		892			

*--4 cosmonauts of this number were studied twice.

**--6 cosmonauts of this number were studied twice.

TABLE 3. RESULTS OF EXAMINING HEALTHY INDIVIDUALS (STANDARDS n=112 PEOPLE). /6

Studied indicators	M±σ	Amount of asymmetry-Δ (D,I)
Otolithic reflex (deg.)	12±7	3
Error in perception of spatial coordinates (deg.):		
a. vertical position	0.67±0.3	5
b. horizontal position on right and left side	18±5	5
Thresholds of cupula receptors (°/s^2)		
a. according to nystagmus	4±2	2
b. according to illusion	3±2	2
Interaction of otolithic apparatus and semicircular canals (s)		
a. duration of nystagmus without postural change	31±9	-
with postural change	22±5	-
b. duration of illusion without postural change	14±6	-
with postural change	9±3	-

in the limits of physiological asymmetry, up to 5°.

In three cosmonauts (FE of the craft Soyuz-22 and Soyuz-T-2, FE of the first expedition of the orbital complex Soyuz-Salyut-6, and the CC of the Soyuz-28 craft), asymmetry was noted in the distribution of /8 indicators for the accuracy of spatial coordinate perception in lateral positions. This was due to a significant excess in the error to 32-38° in the position on the left side. A study of the interaction of the semicircular canals and the otolithic apparatus in 19 of the subjects, including 6 in repeated flights, revealed the reciprocal reactions that were described by V. I. Voyachek. This is a reduction in the reflexes from the semicircular canals in response to the dosed postural change. In five people (FE of the first expedition of the orbital complex Soyuz-Salyut-6, research cosmonauts of the Soyuz-28, Soyuz-30 and Soyuz-31 craft), the dosed postural change after the effect of angular accelerations intensified the recorded reflexes from the semicircular canals.

Data of Cosmonaut Questionnaire

Data were obtained from a purposeful questioning of the cosmonauts on the first day after completion of the space expeditions. In the first flights, all the examined cosmonauts, except three (CC and FE of Soyuz-22 and FE of the third expedition of the Soyuz-Salyut-6 orbital complex) noted illusory reactions mainly of the inversion type ("hanging upside down"), sometimes in the form of shiftings in surrounding objects. In the majority of cases, these reactions developed immediately upon /9 entering weightlessness. In some it developed 2 hours after the transition to weightlessness. In some, the initially developing illusion lasted several minutes, while in others it lasted up to 4 and more hours. It redeveloped periodically during the entire flight, most often when motor activity intensified or under the influence of optokinetic stimuli. Some successfully suppressed the illusions with the help of visual fixation on a certain object, fixation in a chair, as well as by elements of auto-training (relaxing exercises). Fifteen out of 30 examined cosmonauts noted vestibulo-autonomic discomfort in the form of vertigo, nausea, heaviness in the stomach, and sometimes vomiting. The reactions varied in pronouncement and duration (from several hours to 3-7 days). They also differed in time of appearance (from an hour after entering weightlessness to 1-1.5 days). According to the report of 10 cosmonauts, these phenomena were intensified during motor activity. In three, they were intensified under the influence of optokinetic stimulation. Four cosmonauts noted a definite link between the development of vestibulo-autonomic disorders and the appearance of sensations of blood rushing to the head. Different symptoms of blood rushing to the head were observed in all those examined (heaviness in head, nasal congestion, facial puffiness, etc.), however, the majority of cosmonauts did not notice any effect of these symptoms on the development of vestibular discomfort. The noted signs of motion sickness in flight diminished with restricted motor activity, after sleep and rest. It should be stressed that with repeated participation in flights, all the examined cosmonauts observed a reduction in the pronounced nature of the autonomic and sensory reactions during the initial effect of weightlessness. /10

From the reports of the cosmonauts one could conditionally isolate three types of adaptation by the body to the effect of space flight factors: "A"--resistant type: absence of autonomic and sensory discomfort, or weakly pronounced illusory reactions (9 people); "B"--intense but comparatively short period of adaptation (up to 2-3 days) (8 people); "C"--torpid (protracted) type of adaptation, not sharply pronounced symptoms of vestibulo-autonomic discomfor and sensory disorders (7 people). In this group, 2 cosmonauts, according to subjective assessment did not observe signs of adaptation during a 7-day flight.

Data of Post-Flight Examination

In 6 out of the 24 subjects in 0-1 days after flight, sensory reactions were noted (vertigo when turning head and postural change, and in 2 of them, the illusion of tilting downwards by 10-15° when in a horizontal position) and vestibulo-autonomic disorders of varying degree of pronouncement (sensations of heaviness in stomach, nausea, and in 2 of them, vomiting). In this same period. practically all of them observed statokinetic disorders in the form of rocking when walking and instability in Komberg's position. We are not discussing an analysis of these materials in detail because they are covered in a special report of Dr. I. B. Kozlovskaya.

From the materials of the studies we conducted, we can isolate definite trends in the change of studied indicators: otolithic reflex, thresholds of the cupula apparatus, perception function, and to a lesser degree, the nature of interaction between the otoliths and the semicircular canal receptors.

Changes in the function of the otolithic organ were observed on the /11 first-second day both after the long flights (in all the cosmonauts we examined), and after short-duration flights (in 14 out of the 18 examined cosmonauts; in 2 of them during repeated flights). The majority of observations (16) revealed hyperreflexia (two- or one-sided) of the otolithic reflex (21-38° with a normal of 12±7°). One-sided hyporeflexia, a decrease in the reflex from 12° to 5°, was recorded in the CC of the third expedition of the Soyuz-Salyut-6 complex in the first day of examination after the flight.

The second feature of altered otolithic reflex was the appearance of asymmetry that reached 8°-14° (normally to 3°). The reflex asymmetry was more pronounced (to 14°) and was observed in all the individuals who made long flights, and in 4 of the 18 after short flights. Five of the examined cosmonauts showed a change in the directivity of asymmetry after the flight. A tendency towards normalization of the detected shifts was noted after short flights on the second-fourth day. After long flights, it was noted on the eighth-ninth day, and in 2 cosmonauts, in a month after completion of the expedition.

One should make a special examination of the data from studies made on the "zero" day in 8 cosmonauts after short expeditions. In four of them no changes were detected, while in 4 a paradoxical reaction was noted to tilting of the head in the frontal plane (negative otolithic reflex: rotation of the eyeballs towards the tilting). This reaction was recorded in the subjects in 3-5-fold studies. Re-examination of these cosmonauts on the second day after flight did not reveal a paradoxical reaction of the otolithic apparatus. A tendency towards normalization was noted (positive reflex), but its indicators did not always reach the background level. /12

The dynamics for the otolithic reflex after short and long flights is presented in fig. 1.

The thresholds of the cupula apparatus rose after long flights to 10-15°/s^2 in 8 out of 10 cosmonauts (normally to 6°/s^2). During short flights it rose to 8°-17°/s^2 in 8 people.

Sensitivity asymmetry (up to 8°/s^2 with a normal of 2°/s^2) was noted in four people after long expeditions, and in five after short. A tendency towards restoration of the cupula receptor thresholds was observed after short flights on the fourth-fifth day, and in long flights, on the eighth-ninth, and in two people, by the 32nd day. The dynamics for the cupula apparatus thresholds after short and long expeditions is shown in fig. 2.

The accuracy of spatial coordinate perception after a long expedition was disrupted in all the cosmonauts. The error rose in the lateral positions to 38° (normally 18±5°) and in the vertical position to -3°--4°(normally <1°). Assymetry in the indicators in the lateral positions reached 14° (N Δ to 5°). A tendency towards restoration was observed on the eighth-ninth day, and in two people, on the 32nd day.

Analogous shifts were observed after short flights. The error in the lateral positions was also sometimes 38°, and -3° in the sitting position, but in [illegible] of 20 subjects. A tendency towards restoration was noted on the second-fourth day.

The dynamics for change in the perception function in short and long flights is presented in fig. 3.

A change in the interaction between the otolithic and cupula receptors was noted in three studies after long flights. The tendency /13
towards restoration was observed on the eighth-ninth day.

The materials from examining 6 cosmonauts who participated in two flights were compared. Three of them were examined on a full program, while the otolithic reflex in the first flight was not studied in three of them. All the cosmonauts made subjective evaluations of an easier and more rapid adaptation to the effect of flight factors in the second expedition. Five had illusory reactions after the first flight, and one had them after the second flight. Two had autonomic discomfort after the first flight, and one after the second flight.

Objective indicators of disorder in the activity of the otolithic apparatus were found after the first flight in 2 out of 3 subjects, and after the second flight in four out of 6 subjects.

The perception function was disrupted after the first flight in all the cosmonauts, and in four of six subjects after the second flight.

The thresholds of the cupula receptor and its interaction with the otolithic organ were unchanged in both expeditions.

Comparison of the flight tolerance and the data of a background study on the activity of the vestibular apparatus and the perception function demonstrated that good flight tolerance was observed both with unchanged background indicators (in 12 out of 20), and with deviations in the studied parameters (in 3 out of 10). Poor tolerance was noted in 8 out of 20 with a normal background, and in 7 out of 10 with peculiarities. It is apparent from the presented slide that the presence of background functional peculiarities in the activity of the vestibular analyzer and the perception function more often accompany the development of sensory disorders and vestibulo-autonomic discomfort in flight.

Comparison of flight tolerance and the data of post-flight examinations showed that changes in the otolithic reflex were observed in all 8 cosmonauts who were examined after long expeditions with poor flight tolerance in 6 and good tolerance in 2. /14

A change in the otolithic reflex was noted after short flights in 14 out of 18 examined cosmonauts (in 2 after repeated flights). Nine of them had vestibulo-autonomic discomfort in flight. Adaptation to weightlessness occurred in 9 people without symptoms of motion sickness during short flights. After the flight, three of them had normal indicators for the otolithic apparatus activity, and 6 had altered indicators.

Changes in the cupula receptor thresholds (increase and asymmetry) were observed after long flights with the same frequency both with good and poor flight tolerance (four out of ten subjects). The data of the post-flight examination were in the normal limits for two people with different flight tolerance. After short expeditions with poor flight tolerance, changes were noted in six subjects in the threshold sensitivity of the cupula apparatus, and in two subjects the thresholds were in normal limits. With good tolerance of short flights, nine cosmonauts had indicators in normal limits, while three had altered indicators.

After long flights, regardless of the tolerance, changes in spatial perception were recorded in all the subjects (increase in error, asymmetry). After short flights, normal indicators were obtained in 8 with good tolerance and in 2 with development of motion sickness in flight. Changes were noted in 4 with good tolerance and in 6 with poor flight tolerance /15

Conclusion

The effect of the set of space flight factors caused a change in the activity of the vestibular apparatus and the spatial perception function. More significant and longer shifts were observed during expeditions of great duration. The detected disorders (increase in reactivity of the otolithic apparatus, decrease in sensitivity of the cupula receptor, deterioration in the perception accuracy, etc.) had a definite tendency to be restored. The primary damage to the otolithic reflex (changes were found in practically all the subjects) can probably be caused by the specific effect of zero gravitation, and, apparently, may be one of the trigger mechanisms for discrepancy in the activity of the sensory systems, disorders in the correcting function of the cerebellum, and central vestibular formations.

Frequent shifts in the perception function can probably be explained by complex disorders in the coordinated activity of the sensory systems in weightlessness, and a change in the afferent pulses from the otolithic apparatus and other gravitational receptors. One can postulate that a disorder in the activity of the vestibular apparatus in a space flight touches upon the peripheral formations. This can be indicated by an increase in the thresholds of the cupula receptor, changes in the otolithic reflex and interaction between the intralabyrinthine formations. At the same time, the often defined asymmetry in the studied indicators, disorders in the perception function and illusory reactions apparently indicate the involvement of the central vestibular formations (brain stem, cerebellum and cortical representation), as well /16 as the central integrative mechanisms for coordination of the afferent system activity. One cannot exclude the importance of the change in the regulatory mechanisms, neurohumoral factors, and hemodynamic shifts in the development of the body's general adaptive reaction (including the vestibular apparatus) to the effect of flight factors and the post-flight readaptation to conditions of terrestrial gravity.

In order to pinpoint the mechanisms of motion sickness in weightlessness it is necessary to study the neurophysiological plan under space flight conditions, primarily on animals.

Caption for figure 1 /19

Dynamics of Otolithic Reflex after Flights

Key:

circle--commander of first expedition
square--flight engineer of first expedition
hexagon--commander of second expedition
triangle--flight engineer of second expedition
Colored figures correspond to indicators in position on right side, uncolored figures correspond to left side.

Caption for figure 2

Dynamics of Threshold Sensitivity of Semicircular Canals after Flights

Key:

circle--commander of first expedition
square--flight engineer of first expedition
hexagon--commander of second expedition
triangle--flight engineer of second expedition
Colored figures correspond to increase in velocity, uncolored figures correspond to a decrease in velocity.

Caption for figure 3 /20

Dynamics of Indicators for Perception Accuracy of Spatial Coordinates in Lateral Positions after Flights

Key:

circle--commander of first expedition
square--flight engineer of first expedition'
hexagon--commander of second expedition
triangle--flight engineer of second expedition
Colored figures correspond to indicators in position on right side, uncolored correspond to the left side.

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