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MECHANISMS FOR VESTIBULAR DISORDERS IN SPACE FLIGHT.
FACTS AND HYPOTHESES

E. I. Matsnev

Translation of "Mekhanizmy vestibulyarnykh narusheniy v kosmicheskom polete. Fakty i gipotezy," Institute of Medical and Biological Problems, USSR Ministry of Public Health, (Report presented at the 11th Joint Soviet-American Working Group on Space Biology and Medicine, Moscow, October 1980), 1980, pp 1 - 33 (without figures)

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16. Abstract This article discusses the vestibular disorders associated with space flight. It is found there is still no complete understanding of the changes occurring in the sensory systems of the body during weightlessness. Results of studies are presented, including results of a ground model.			
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MECHANISMS FOR VESTIBULAR DISORDERS IN SPACE FLIGHT.

FACTS AND HYPOTHESES

E. I. Matsnev

Introduction

We currently no longer have to doubt that the disorders linked /1* to the vestibular system, in particular, disorders of spatial orientation, and symptoms of so-called space motion sickness (MS) in cosmonauts are one of the most urgent problems of space medicine.

The lack of basic research on the effect of weightlessness on the sensory systems that guarantee static and dynamic spatial orientation, control of posture and equilibrium of the body, to a considerable measure impairs the understanding of the etiopathogenesis of these disorders. In this respect our ideas on the mechanisms for the vestibulo-autonomic and sensory disorders in cosmonauts still have a hypothetical nature today. Nevertheless, definite factual material has been accumulated by now on the phenomenology for the development of spatial illusions and MS in cosmonauts. Results have been obtained from flight and post-flight studies of the vestibular function of cosmonauts who have made short and prolonged space flights. A cycle of ground model experiments has been made that permits certain considerations to be advanced for the possible mechanisms for vestibular disorders in space flight.

Before passing to an examination of these mechanisms, it is expedient to briefly state the phenomenology of those vestibulo-autonomic and sensory disorders that occurred in the cosmonauts in short and

* Numbers in margin indicate pagination in original text.

prolonged space flights, for this information has great significance in an understanding of the complicated changes that occur in the sensory systems of the body in weightlessness.

1. Phenomenology of the Development of Spatial Disorders and Vestibulo-Autonomic Disorders in Cosmonauts in Flights of Varying Duration

By summarizing all the cases of MS and illusion of spatial perception that have occurred in manned flights of Soviet cosmonauts one can note that the vestibulo-autonomic disorders that are similar to the symptomatology of motion sickness on earth, were found in every third cosmonaut, while the symptoms of disrupted spatial orientation or elements of disorientation were found in the overwhelming majority of cosmonauts. These statistics indicate that MS and spatial disorders are not the fate of individuals, but are a natural reaction of a considerable number of individuals who are in conditions of zero gravity.

Spatial illusions in a space flight are characterized by diversity of manifestations and great individual variability. Certain cosmonauts with open and closed eyes noted the illusion of the position of "head down", "face down", "feet up", "overturning", "falling", "hovering", "separation from chair" that often combine with elements of disorientation [1,9,11,12,13,15,23,25,26]. Individual cosmonauts noted the illusion of "convergence" or "shifting" of the instrument panel [12], feeling of "false" sensation of rotation of the craft with open and closed eyes at the moment the body was separated from the floor. With closed eyes a sensation of body rotation appeared which disappeared when the cosmonaut pressed his head to the floor [18]. Under conditions of complete darkness or during free "floating" in the craft compartment with closed eyes the condition of partial or complete disorientation occurred [13,15].

In evaluating the subjective sensations from the position of spatial perception during a space flight, certain cosmonauts isolated the absolute absence of an idea about height in weightlessness. All the space in the craft or outside the craft is represented in concepts of

distance and depth, but not height [9].

The entire idea of space and the cosmonaut's position in it is possible in weightlessness thanks only to the visual correlation. When vision is excluded orientation and perception of the surrounding space are completely lost [7].

The perception in weightlessness of linear accelerations that develop when the engines are engaged that are used to correct the craft orbit is evaluated by some cosmonauts as an adequate slow movement, and by others as an excessively intensive movement. After the engines have been disengaged for several seconds the feeling of continued movement remains [39].

Certain cosmonauts have successfully suppressed the illusion either with the help of visual fixation of some object or rigid fixation of the body in a chair, or with the help of self-training.

In analyzing the frequency of the illusory sensations in the cosmonauts one can note that the first place for frequency of manifestations was occupied by illusions of overturned body (inversion), followed by illusions of displacement of objects, tilting, falling and rotation of the body. The illusory sensations were noted suddenly in most of the cases, immediately at the moment of transition to weightlessness. They gradually decreased in the space of several hours. However in individual cosmonauts the illusory sensations were maintained for several days of the flight or even during the entire flight [2,9].

As a rule the illusory sensations were not accompanied by a disruption in the spatial orientation and performance capacity. /4

In the opinion of the cosmonauts the illusory sensations during the flight were very close to those sensations that they experienced during the parabolic flight conditions [28].

Attention is drawn to the fact that certain cosmonauts link the development of illusory sensations to the "influx" of blood to the

head in the "acute" period of adaptation to weightlessness (puffiness of the face, stuffy nose, heaviness in head, etc.).

There is no clear confirmation of the link between the illusory sensations and the symptoms of vestibulo-autonomic disorders. Although the illusory sensations can be combined with symptoms of MS, nevertheless the impression is formed that these symptoms develop independently. The conclusion suggests itself that the illusions are not the primary sensory reactions of MS preceding the autonomic disorders, and in this respect one can suggest their independent mechanism for development.

The manifestations of MS symptoms in space flight are also characterized by considerable variability. The data of the cosmonauts' reactions of the vestibular apparatus in weightlessness are contradictory at times. Thus, according to the evidence of some cosmonauts the vestibular reactions in the first days of flight are similar to the sensations experienced on earth under the influence of Coriolis accelerations [2,7,9,12,13,15]. In the opinion of other cosmonauts, sharp head movements, especially in the first days of flight, cause a unique sensation in the vestibular apparatus that is not similar to any of the sensations that developed during the vestibular stimulation on earth [8]. Some cosmonauts indicate that the vestibular apparatus in weightlessness seemingly is transformed into a very sensitive "inertia-accelerometric sensor," while others note a clear reduction in the sensitivity, lower sensitivity of the vestibular apparatus to the perception of adequate vestibular stimuli. /5

However the majority of cosmonauts are unanimous in the opinion that increased motor activity, especially sharp head and torso movements in the first days of the flight are the main stress factor that provokes MS symptoms.

MS symptoms in weightlessness developed and were maintained for a varying time in the initial flight stage, from the first minutes and hours of the flight to 6-7 days. They were characterized by an

unpleasant sensation of heaviness in the epigastric region, a feeling of "elevation" of the stomach in the initial stage, and with pronounced manifestations--nausea and vomiting. After vomiting the condition of the cosmonauts somewhat improved. Eating in this period often promoted vomiting. In individual cosmonauts on the background of vestibular discomfort more frequent urination was noted [28].

During the development of MS many cosmonauts experienced a feeling of asthenia, apathy, drowsiness, a desire to rest and to not move. They noted heaviness in the head and in the area of the eyebrows, unpleasant sensations in the area of the eyeballs, especially during their movements, headache and drastic loss of appetite [10].

At the same time the fulfillment of important working operations promoted a reduction in the phenomena of discomfort and attracted attention away from the unpleasant sensations. Sleep significantly improved the state of health and reduced the manifestations of MS [8,9].

Optokinetic stimuli (OKS) are capable of intensifying the manifestations of MS in space flight. Thus, the OKS linked to tracing objects outside the craft intensified the manifestations of MS [1,7]. According to the testimony of a number of cosmonauts of the orbital station Salyut-6, the provoking moment in the development of MS was optokinetic stimuli, as well as the absence of the customary feeling of support and a sensation of "upside down." At the same time, the cosmonaut-researcher of the spacecraft Soyuz-31 reported that observation of the earth's surface in a porthole window in the state of vestibular discomfort promoted the reduction of these phenomena for him [28]. /6

It needs to be noted that a considerable number of cosmonauts focused attention on the fact that the transition from the transport craft to the orbital station, as a rule, promoted the intensification of vestibular discomfort [9, 13, 20].

By analyzing the nature of the adaptive reactions of the cosmonauts to weightlessness, one can draw the conclusion that in the prac-

tice of manned flights of Soviet cosmonauts there has not yet been a case where the cosmonaut who had symptoms of MS in the final analysis could not adapt to the weightlessness conditions. At the end of the period of adaptation the cosmonaut can complete the most diverse and sharp movements, and they no longer provoke any unpleasant vestibular reactions. Attention should however be drawn to the fact that in the commander of the crew of the second (main) expedition of the orbital station Salyut-6 that made a 140-day flight, 10 days before the end of the flight slight vestibular discomfort again appeared with an increase in motor activity (sharp rotations of the head and torso) [28].

In the post-flight period, in a considerable number of cosmonauts disorders were noted in the function of postural equilibrium, especially in the absence of visual landmarks, unstable walk, and deviation from the center of gravity in the stabilographic study [18, 19, 24]. After brief flights the restoration of the initial level of postural equilibrium occurred in the space of several days. After prolonged flights this period increased to several weeks. For example, after a 140-day space flight on the orbital station Salyut-6 even on the 26th day of the post-flight period considerable disorders in the activity of the postural regulation system were found in the crew of the second (main) expedition. /7

In individual cosmonauts (cosmonaut-researcher of the spacecraft Soyuz-31 and others) on the second-third day of the post-flight period upon awakening (for several seconds) a distinct illusion of inversion was noted.

In certain cosmonauts, for example, the commander of the second expedition of the orbital station Salyut-4, several hours after landing, with rapid turns and rotations of the head the development of a vestibular symptom complex was noted (of the acute labyrinthopathy type) that was characterized by sharply pronounced vertigo, nausea, unpleasant sensations in the epigastric region, pallor of the skin integuments, and drop in appetite. A noticeable improvement occurred

after taking a preparation against MS ("plavefin"). The listed symptoms disappeared 1.5 days after the second night of sleep [2,10].

In concluding this brief generalization of the phenomenology of spatial illusory disorders and MS in a space flight, one should stress again the extreme variability of the manifestations of these disorders, the sequence of development, the degree of their pronouncement, etc. The distinct link between MS and the motor activity of the cosmonauts permits the assumption that the primary and essential factor of MS in weightlessness probably has a vestibular origin.

2. Results of Certain Studies of the Vestibular Function and Function of Perception of Space in Cosmonauts Who Have Made Short and Prolonged Space Flights

The studies made in recent years on the vestibular function and the function of spatial perception in cosmonauts who have made short and prolonged space flights on the craft Soyuz and the orbital station Salyut permitted the obtaining of a number of new facts that broaden our ideas about the effect of weightlessness on the sensory systems of the human body.

Based on qualitative and quantitative characteristics of the postural mechanisms for spatial orientation in the cosmonauts who have made an 18-day flight on the craft Soyuz-9 an attempt was made to evaluate the role of signalling of the vestibular, proprioceptive and tactile analyzers, and the nature of their interaction to the development of illusory sensations in flight (A. D. Matveyev). For these purposes a study was made on the commander and flight engineer before the flight, in the flight and in the post-flight period using the instrument 'Vertikal'-B. The studies covered the accuracy of the visual and tactile-kinesthetic determination of external and internal coordinates of space depending on the different conditions and the degree of postural signalling (standing vertically, lying on side, with fixed legs, without fixing, when only the head was fixed to the instrument in flight, while the legs and torso did not touch the

surrounding objects and the walls). In order to exclude or weaken the visual memory, each study was preceded by a preliminary 3-minute dark adaptation. The studies were conducted with binoculars.

In determining the directions of the coordinates in flight with open eyes (visual-tactile-kinesthetic evaluation) the cosmonauts in each study permitted more significant errors than before the flight (fig. 1,2). A clear dependence was traced of the results on the method of fixation. Determination of the tactile-kinesthetic (not visual) coordinates was disrupted to a great degree. There was an especially significant disorder in the tactile-kinesthetic coordinates mainly in the post-flight period.

The qualitative nature of errors in the position of standing and lying was approximately the same. In a quantitative respect the errors in determining the vertical were more pronounced, especially in the lying position and in the tactile-kinesthetic method. On the contrary, in the first post-flight examination a considerable difference was noted in the error between the visual and tactile-kinesthetic determination of the coordinates in the position of standing and lying. Even on the 20th day of the post-flight period the size of the difference in the error was higher than the background by several times. /9

The limited nature of the flight material does not permit categorical judgments about the physiological mechanisms for spatial orientation in weightlessness; nevertheless, in combination with the regularly conducted post-flight studies on the function of spatial perception one can compare and analyze the features of orientation in weightlessness from the position of the values of the visual and tactile-kinesthetic mechanisms.

The results of these studies, like the subsequent observations, indicate that changes in the postural signalling from the receptors of the vestibular, proprioceptive and tactile analyzers are practically not reflected in the visual perception of space. This is confirmed

by the good performance capacity of the cosmonauts during the entire flight. Visual orientation in space, despite the change in the incoming sensory information, guarantees fairly rapid adaptation of the sensomotor coordination in flight. Under conditions of visual field without orientation, or constricted field, in complete darkness, in crepuscular illumination or with closed eyes the orientation mechanisms in weightlessness are evidently different than those on earth. In a field without orientation in weightlessness the size of the systematic error with visual and tactile-kinesthetic methods of evaluating the position of external spatial coordinates is increased, especially in the latter method. One can look at two mechanisms that are responsible for the size of error in the tactile-kinesthetic method of coordinate determination. The first can be linked to the insufficiency of the postural information due to the dropping out of distant signalling from the otolithic gravity receptors. The second mechanism consists of the incompleteness of the sensomotor coordination in the absence of visual control. It is known that the sensomotor coordination is disrupted in the first days of the flight, in the period of so-called "acute" adaptation to weightlessness, then the "surplus" movements of the cosmonauts disappear. /10

The results of spatial coordinate determination with fixation of the cosmonauts in two or one point and different body positions indicate on the one hand, the great importance of tactile-proprioceptive information for nonvisual orientation in space, and on the other hand, the presence of a latent insufficiency of the sensomotor coordination. Apparently under conditions of a loss of distant reception of the otolithic apparatus the role of the local receptor system of tactile and proprioceptive analyzers rises in orientation. This is demonstrated by the data obtained during fixation of the cosmonauts at one or two points. The absence of gravity effects thus changes the process of orientation and places it in direct dependence on the tactile and proprioceptive sensations.

The noted peculiarity of the combination of visual and tactile-

kinesthetic coordinates in flight indicates that in weightlessness with symmetrical body muscle tone at rest and the absence of visual orientation the subjective vertical, i.e., the visual and tactile-kinesthetic idea about the position of the true external spatial coordinates depends on the position of the longitudinal body axis. One /11 can probably say that orientation in weightlessness in the absence of visual control is linked to subjective sensations of the position of the body symmetry axis based on tactile-kinesthetic perception of space. With new sensory control where the system of tactile-proprioceptive analyzer become the basis for constructing a sample of space and a body plan, the subjective evaluation of the coordinates fluctuates in individual limits. The adaptation process depends on the degree of trainability, the degree of instruction of the cosmonaut, and his familiarity with an analogous situation of tactile-proprioceptive control.

The findings indicate that in the period of adaptation to weightlessness, and then readaptation to conditions of terrestrial gravity, great lability and instability for a subjective evaluation of the position of the external coordinates of space develop. This is apparently linked to the drastic change of the stimuli of postural reception in each new medium. This leads to a change in the tone of the skeletal musculature and causes disorders in the coordinated body plan with the position of the external coordinates, and as a result in difficulties and errors in orientation.

As for the determination of the direction for internal (corporal) coordinates based on a subjective evaluation of the position of the longitudinal and transverse body axis, the results of determining the position of the body axis practically did not differ from an evaluation of the external coordinates. This is apparently explained by the fact that under flight conditions the true direction of the body axis corresponded to the objective direction of external vertical and horizontal spatial coordinates.

As already noted above, in the absence of tactile sensations (without fixation of the body) and with free floating in weightlessness with closed eyes any idea of the body position and spatial coordination /12 is lost. For orientation within the craft with closed eyes or in complete darkness it is necessary to have sufficient area of body or arm contact with objects or the frame of the spacecraft. For orientation with objects outside the compartment and for making different craft maneuvers (change of orbit, orientation and docking of the craft, etc.) it is necessary to have accurate orientation of the body plan of the cosmonaut in relation to the craft axes. With different types of work and studies, for example, for conducting astro-orientation in complete darkness, the spatial sensations can be based only on a tactile feeling.

In weightlessness the close functional link of tactile and proprioceptive analyzers is probably intensified and represents the basis for constructing a new system of interaction of analyzers that compensates for the partial dropping out of distant orientation due to the absence of the gravity function of the otoliths. With the absence of vision these two systems are apparently the basis for local and distant orientation in weightlessness.

One can thus hypothesize that during a prolonged stay in weightlessness due to the change in the gravity receptor function and muscle tone the system of analyzer interaction that was formed on earth is disrupted. It is still not clear what these mechanisms and the mechanisms for their compensation are, and what is the role of the otolith apparatus in this process.

Objective data about the condition of the vestibular apparatus functioning in the "acute" period of adaptation to weightlessness are currently limited mainly to studies of the vestibulo-somatic reaction, type of graphic evaluation of vertical writing, supplemented with a series of dosed head movements in different planes. The studies made /13 by the crew of the craft Soyuz-8 on the fourth day of flight with the use of a special plotting board for recording letters revealed an

intensification in the vestibulo-tone reflex that under ground conditions is usually characteristic for an increase in excitability of the cupulo-endolymphatic system for adequate stimuli. These indirect data are of course clearly insufficient for a judgement about the degree of sensitivity of the cupulo-endolymphatic system of the cosmonauts in the period of adaptation to weightlessness, however, with regard for the research of Baumgarten [30] an increase in the sensitivity of the semicircular canals to adequate stimulation in this period is quite logical.

As is known, the program of pre- and post-flight clinical and physiological examination of the crews from the craft "Soyuz" and the orbital station Salyut included a number of studies of the vestibular function and the function of spatial perception [20, 21, 28, 51]. An evaluation was made of the otolithic reflex by the method of direct otolithometry according to De Wit [34] and Fluor [35], the function of the semicircular canals according to the amount of perception of angular acceleration thresholds (according to nystagmus and the sensory reaction), study of the interaction of the otolithic organ and the semicircular canals ("otolithic reaction" of V. I. Voyachek), study of the function of spatial coordinate perception with the use of the 'Vertikal' instrument [3,50]. Detailed data about the results of these studies will be presented in a separate report (I. Ya. Yakovleva, L. N. Kornilova, et al.).

The most important result of these studies is the established fact of an increase in the reactivity of the otolithic apparatus in the cosmonauts after a space flight. Even with regard for a critical attitude to the accuracy of the employed method of indirect otolithometry, the trend towards post-flight hyperreflexia of the otolithic reflex is not doubted. Such an increase in the reactivity of the otolithic function can apparently be interpreted in direct tie to the process of readaptation, i.e., the effect of terrestrial gravity on the otolithic organ. Further accumulation of data will apparently

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permit a more convincing answer to the question of whether this phenomenon is a natural phenomenon indicating the adaptation process of the otolithic organ to terrestrial gravity. The fact that normalization of the otolithic function occurred in parallel to the restoration of the function of postural equilibrium can indicate that a change in the input otolithic signals after the flight has great significance for the functioning of the postural, statokinetic system.

Attention should be given to the detection of the phenomenon of asymmetry in a number of vestibular characteristics (otolithic reflex, threshold sensitivity of the semicircular canals, function of spatial perception, and others) in the cosmonauts after completion of a flight. It is important to note that in studying the postural equilibrium the tilting of the body or fall generally occurred towards the labyrinth with the higher hyperreflex activity. One can hypothesize that such asymmetry is linked to a disorder in the dynamic equilibrium between the vestibular organs of the right and left sides, and is a reflection of those complicated functional changes that occur during the prolonged absence of gravity stimuli in the vestibular, tactile, kinesthetic and neuromuscular sensory mechanism, especially in the central regulatory mechanisms. The importance of the "imbalance" in the activity of the paired vestibular apparatus governed by the leveling of the weight of the otolithic membranes in weightlessness or individual bilateral asymmetry of the weight of the otolithic membranes is stressed in publications [16, 31]. It is not excluded that the dominance of the functional activity of a certain cerebral hemisphere that is well compensated for under normal conditions on earth, begins to appear after man's prolonged stay in weightlessness. At least in the ground experiments with simulation of the effects of weightlessness (antiorthostatic hypokinesia) we often observe the appearance of asymmetry in the reflex excitability of the labyrinths after the subjects stay under these conditions [5].

In a comparison of the short and long space flights it becomes evident that there is a direct dependence of the disorders in the

function of the postural, statokinetic system on the duration of the flight. Studies of the motor apparatus and the system of regulating the motor function in cosmonauts who have made prolonged space flights revealed significant changes in the condition of the spinal reflex mechanism. These changes are expressed in an increase in the sensitivity to the muscle afferent input, disorders in the interextremity reflex interactions, increase in the electromyographic cost of the muscle effort, and reduction in the maximum amount of the reflex response [19]. Thus, in the cosmonauts of the second main expedition of the orbital station Salyut-6 who made a 140-day space flight, in the post-flight period considerable changes were noted in the work of the mechanisms for maintaining a vertical position (recording of tremors with frequency of 7-9Hz in the electromyographic and stabilographic study), especially with closed eyes and load tests. With random tilting of the body, the postural reconstructions were made with a large delay, their duration increased, and the coordination structure changed distinctly [19]. There are grounds to assume that during a prolonged stay in weightlessness the sensory systems that are responsible for maintaining postural equilibrium are exposed to considerably greater changes than in short flights. In this respect one can apparently agree with the opinion of Homick (1977) who believes that in short flights the changes in the signals from the kinesthetic, tactile, proprioceptive and otolithic receptors have a primarily peripheral nature. On the central level of the nervous system stable habits of acclimatization are still not successfully formed. In prolonged space flights, a stable mechanism of acclimatization is probably formed on the central level of the nervous system [41, 42, 43]. The longer the flight, the more complicated the process of nerve reconstruction, and adaptation of the activity of kinesthetic, tactile and otolithic receptors to terrestrial gravity.

Ground model experiments that reproduce the effect of negative effects of weightlessness on the human body, including on the sensory systems yield important information for an understanding of the mechanisms of MS in space flight.

3. Hypotheses on the Genesis of Space MS. Results of Ground Model Experiments.

Two main hypotheses about the development of MS in space flight are currently being actively discussed and experimentally substantiated.

One hypothesis explains the development of space MS from the position of a "sensory conflict" [49]. According to this hypothesis, the transition of man to a condition of weightlessness is accompanied by the arrival of unusual signals to the central nervous system, mainly from the otoliths, as well as from the visual system, proprioceptors, etc., in other words, discrepancy in the sensory afferent inputs. The arrival of such information that is contradictory as compared to terrestrial conditions, does not permit the body to rapidly solve this "sensory conflict." This results in the development of MS.

Recently a number of experimental data have been obtained that could /17 support the hypothesis of "sensory conflict" [35, 50]. These studies stressed the role of the visual-gravitational interrelationships, and the visual-vestibular-somatosensory conflict as one of the possible mechanisms for the development of MS in weightlessness. For example, in the experiment with 7-day stay of 10 healthy people under conditions of immersion it was shown how significant the effect is of a discrepancy in the vestibular and proprioceptive efferent inputs on the eye-movement reaction that participates in the act of tracking (I.B. Kozlovskaya). By using the reaction of aiming gaze that is formed, as is known, from three components (saccadic movements, turning of the head and slow counter-return of the eyes) and whose coordination reliability is guaranteed by the vestibular input, it was established that under conditions of immersion there is a considerable reduction in the accuracy of regulating this reaction. This was indicated by the lengthening of the time for aiming the gaze by more than 100 ms. and the development of additional correcting saccadic movements. Analysis of the data indicated that these changes were linked to an increase in the velocity of individual components and a disorder in

the interaction between the maximum velocity of the eye counter-return and the head. After immersion, the sensitivity of the vestibular apparatus increased. This was indicated by the reduction in thresholds for deviation of the eyes during galvanic stimuli of the labyrinths. The results of this experiment indicate that a reduction in the proprioceptive signalling governs the increase in excitability of the vestibular input that is evaluated according to the eye-moving reactions. One can hypothesize that normally proprioception has a braking effect on the activity of the vestibular neurons and that the given nature of interaction is universal for the proprioceptive and vestibular systems.

It was previously [22] demonstrated that a 56-day stay by healthy /18 people in immersion, according to the data of calorizing of the labyrinths by the method of Fitzgerald and Hallpike, results in hyper-reactivity of the vestibular analyzer that is characteristic for an increase in excitability of the central vestibular neurons. This could be linked to a reduction in the braking spinal-vestibular afferent inputs from the antigravity musculature to the vestibular system. The Japanese researchers [47] came to an analogous conclusion. They noted signs of hyperreflexia of the caloric nystagmus in healthy individuals during water immersion. The hyperreflexia rose proportionally to the drop in body weight and weakening of the antigravity musculature.

At the same time it should be admitted that the employed ground models of the "sensory conflict" are very far from that situation that could be assumed in a real space flight. Without negating the value of ground simulation of the "sensory conflict" for an understanding of this complicated psychophysiological process, it would nevertheless not be a large error to admit that only direct studies under space flight conditions will permit final proof to be obtained for the correctness of this hypothesis.

The second hypothesis is based on the link between the movement of fluid media of the body in a cranial direction in weightlessness

and the development of MS [8]. This hypothesis is based on the assumption that the redistribution of fluids in the body, and the increase in intracranial pressure that is linked to this are capable of leading to a disbalance in the labyrinthine fluids with a subsequent disorder in the vestibular neuronal conductivity, biochemical changes in the endolymph, etc. It is not excluded that both hypotheses can coexist, and in this case we should speak of the isolation of the specific weight of the sensory or hemodynamic component in the genesis /19 of MS in a space flight.

Studies of human susceptibility to MS after staying in conditions of antiorthostatic hypokinesia (ANOH), as well as measurements of the intracranial and intralabyrinthine pressure in animals who were in analogous conditions [14,36,48] raised doubt about the role of the movement of fluids in the body in a cranial direction as the main etiological factor in the development of MS. Thus, in the research of [14] it was shown that a 2-hour stay in ANOH (-20° and -30°) and a 7-day ANOH (-6°) do not have an adverse effect on the tolerance of cumulative vestibular loads, despite the pronounced shifts in the system and intracranial circulation (increase in cardiac discharge, reduction in peripheral resistance to blood flow, decrease in the pulse blood filling of the intracranial vessels, decrease in the orthostatic stability). The question arises as to whether, by orienting ourselves on these studies, we can completely repudiate the importance of the hemodynamic factor in the genesis of space MS. Today this would be premature because the method features of the mentioned experiments (absence of special selection of the subjects according to original vestibular stability, of critical measurements of endolymph pressure in the research of Parker) did not permit the authors to draw categorical conclusions about the etiological role of the movement of fluids in the development of MS.

At the same time, the studies of the reflex excitability of the labyrinths in individuals who are in conditions of ANOH reveal the far from equivalent individual reaction of the human vestibular

system to these conditions [5]. After generalizing the results of a study on the vestibular function of 50 healthy individuals in age from 21 to 43 who participated in experiments with ANOH lasting from several days to 182 days with angle of antiorthostasis from -4 to -12° , we conditionally isolated three types of functioning of the vestibular system: I (compensated type) noted in roughly 55% of the subjects was characterized by the minimum changes or the absence of changes in the vestibular function with rapid restoration of the function of postural equilibrium; II (subcompensated type) noted in 30% of the subjects appears as hyporeflex directivity to the labyrinth reactions during calorizing in the ANOH with a simultaneous sharp increase in the sensitivity to angular accelerations after hypokinesia; III (decompensated type) was found in 25% of the subjects and was characterized by pronounced hyperreflexia of the labyrinth reactions during caloric and rotational tests (fig. 8). For the subjects with the II and III types of reactions there was a characteristic presence of vestibulo-cerebellar asynergy, pronounced disorders in the postural equilibrium with lengthy period of restoration. The caloric and post-rotational nystagmus of the last two categories of subjects was characterized by asymmetry of the labyrinthine reactions, prevalence of the nystagmic reaction according to direction, dysrhythmia and signs of reversion (fig. 3,4). /20

Recording of dysrhythmia of caloric nystagmus in individuals during ANOH does not exclude the possibility of vascular changes in the region of central (stem) vestibular formations [29]. Certain authors [40, 46] are generally prone to view dysrhythmic nystagmus as a pathognomonic sign of central vestibular dysfunction that indicates disorders in the transmission of nerve impulses from the vestibular nuclei and from the reticular formation to the oculomotor nuclei. This is manifest in a disorder in the rhythm of nystagmus. It is important to note that similar dysrhythmia of the caloric nystagmus was observed by the specialists from the FRG [44] in a situation opposite to ANOH, i.e., under conditions of the efflux of blood to the lower half of the torso (ODNT). They also are prone to explain the disorder in /21

nystagmic rhythm in relation to cerebral vascular shifts that result in a change in the functioning of the vestibular centers in the area of the brain stem.

The detection of vestibulo-autonomic reactions in individual subjects of this group during caloric and rotational tests, dissociation between the caloric and post-rotational nystagmus, and paradoxical phenomenon of the appearance of autonomic reactions on the background of pronounced inhibition of the caloric nystagmus indicates that the vestibular apparatus of these individuals is far from being indifferent to the ANOH conditions.

In this aspect it is important to look at the results of a recently conducted experiment (V. K. Katkov, E. I. Mantsev) with a 3-hour stay of 5 male volunteers in ANOH (-20°) in which the condition of the reflex excitability of the labyrinths by the method of thermal calorizing [32] was evaluated in parallel to a study of the general and cerebral hemodynamics, as well as the metabolic activity of the brain by selective probing of main vessels. The studies revealed a reliable reduction in the reflex activity of the labyrinths (fig. 5). In this experiment, as in the previous studies, a distinct individual reaction of the vestibular system of the subjects was noted to the antiorthostatic position (from moderate hyporeflexia to areflexia in one subject). The typical pattern of the ENG reactions reflecting the decrease in the reflex activity of the labyrinths by the end of the third hour of stay under ANOH conditions is presented in fig. 6. Implementation of the dynamic ENG control during the entire experiment permitted recording in the given subject of spontaneous horizontal nystagmus at 2 hours and 45 min. of ANOH (fig. 7). In another subject nystagmus was noted during his transfer from the position of ANOH to a horizontal one. /22

In 3 out of 5 subjects calorizing of the labyrinths at the end of ANOH was accompanied by a pronounced autonomic and sensory reaction.

By the end of the third hour of ANOH reliable changes were noted in the majority of parameters that characterize the central circulation (increase in cardiac discharge, change in systolic and diastolic component of pressure in the internal jugular vein, drop in the arterial-venous difference for cerebral and system circulation). A change was also noted in the acid-base equilibrium of blood. At the end of the exposure to ANOH an increase in the ATP concentration, and decrease in the concentration of pyruvic acid and concentration of potassium ions were observed in the blood flowing from the brain.

Thus, proof was obtained that a 3-hour stay in ANOH (-20°) has an unfavorable effect on the functioning of the vestibular system of individual people. The detection of reliable hyporeflexia of the caloric nystagmus on the background of autonomic and sensory reactions, the detection of spontaneous and dysrhythmic nystagmus, and asymmetry in the nystagmic reaction in certain subjects is a confirmation of this conclusion.

It is not excluded that the presence of a "stress-reaction" that undoubtedly occurred during such manipulation as catheterization of the main vessels could influence the nature of the caloric nystagmus reaction. There are indications in the literature that the "stress-reaction" results in a decrease in the effectiveness of the vestibular system and has an inhibiting effect on many functions of the vestibular system [45]. At the same time the detection of spontaneous and dysrhythmic nystagmus, vestibulo-autonomic and sensory reactions in individual people can hardly be linked only to the stress reaction and does not exclude the unfavorable effect of ANOH on the vestibular function. /2

The results of these studies indicate the need for further research to investigate the effect of movement of the bodily fluids on the condition of the vestibular system, and pinpointing of the reasons for unfavorable reactions of the vestibular apparatus of individual people to this effect.

In correctly doubting the importance of cerebral hemodynamic shifts in weightlessness as the main and primary etiological factor in the development of space MS, we nevertheless must evaluate the specific weight of these changes as a concomitant factor in the general complex of etiological factors for MS.

Conclusion

The presented materials indicate that in recent years a number of important facts have been obtained that pinpoint the individual aspects of the problem of vestibular disorders in space flight. It would nevertheless be correct to admit that today we are still far from a final understanding of those complicated sensory disorders that are the basis for the mechanisms of spatial disorders and MS in cosmonauts in space. /24

None of the currently advanced working hypotheses on the genesis of MS in weightlessness has been completely refuted, and consequently, they all have the right to exist.

It is necessary to note that the discussed hypotheses do not at all consider fully a number of important factors that can have an adverse effect on the functioning of the vestibular system in weightlessness and are the aggravating moment in the development of MS.

We have thus not received the proper experimental evaluation for the importance of the biochemical shifts in the blood during the redistribution of fluids to the upper half of the torso (especially disorders in the electrolytic balance) as one of the important components of the negative effect on the function of the vestibular receptors. At the same time it is known that a close osmotic link exists between the perilymph, the blood system and the cerebrospinal fluid, while the potassium ions are actively transported from the perilymph to the endolymph. Attention should also be drawn to the information that increased release of fluids from the body predisposes the system to a disorder in the transport of water and potassium ions

between the endo- and perilymph.

There has not been a sufficient evaluation of the effect of a drop in the tone of the antigravitational musculature of individual muscle groups in cosmonauts, especially the neck musculature, on the activity of the neck-oculomotor system, etc.

In this respect it is important to describe a theoretical model of MS that considers most fully all the possible mechanisms for disorders in the sensory systems, and in the final analysis result in the development of MS. With regard for this model it would be purposeful to work out not only the basic but also the applied questions of this problem, in particular, to search for pharmacological and non- /25 pharmacological means of prevention and therapy for MS in space flight, i.e., until now it has mainly been conducted by an empirical method.

The first attempts to use the "pathogenetic" approach to formulating means of preventing MS have showed its promise.

With regard for the possible role of specific optokinetic modulation of estibular MS that results either in inhibition or in intensification of the MS symptoms it becomes possible to actively influence the MS by physical methods, for example, by reducing or eliminating the visual-vestibular-somatosensory conflict during motor activity in weightlessness [37,38].

By evaluating different groups of pharmacological resources from the position of the importance of the etiological role of the hemodynamic factor in the development of MS in weightlessness, promising data were obtained with the use of the administration of derivatives of vinkamin (ethylapovinkaminate-"Kavinton" of the firm Gedeon Richter, Hungarian People's Republic) as a means of prevention and therapy for experimental MS [4,6]. If further research in this direction confirms the effectiveness of an analogous class of preparations, then a future will open up for developing nontraditional pharmacological resources for preventing MS.

Another trend in this research is the search for physical resources that could influence the nerve or biochemical processes in the area of individual central structures of the CNS with respect to the possible active control of the vestibular adaptation of man in altered gravity conditions. For example, the use for these purposes of square electrical currents with galvanic component demonstrated the fairly pronounced protective effect of this method against MS under laboratory conditions. /26 The combination of this effect with pharmacological resources against MS (seduxen, cyclodol) unexpectedly revealed the capacity of the electrical impulse effect to potentiate the protective properties of these preparations against MS. In preliminary studies on animals using electrodes implanted in their brain it was established that the greatest current density during the impulse effect of square currents occurs on such cerebral structures as the hypothalamus and limbic system whose significance in the regulation of the autonomic functions and vestibular function is generally known.

Future research will show whether the nonpharmacological methods can compete with the traditional pharmacological resources, however the promising nature of a further search in this direction is evident.

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Captions for figures of article of E. I. Matsnev "Mechanisms for Vestibular Disorders in Space Flight. Facts and Hypotheses"

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Figure 1. Dynamics of error in determining vertical in commander of spacecraft Soyuz-9

Figure 2. Dynamics of determining vertical in flight engineer of spacecraft Soyuz-9

Figure 3. Caloric reaction of right labyrinth in "thermal" calorizing of subject Sh-v, 32 years old, in period of 182-day ANOH and in period of readaptation:

1--background; 2--4th day of ANOH, 152nd day of ANOH; 3--30th day of readaptation period

Figure 4. Dysrhythmia of post-rotational nystagmus detected in subject A-v, 37 years old, on 3rd day of readaptation period after 182-day stay under conditions of ANOH under effect of angular accelerations ("stop-stimulus" $180^\circ/\text{s}$).

Conventional designations:

Two upper curves--ENG and EKG before experiment;

Two middle curves--ENG and EKG on third day of readaptation period;

Two lower curves--on 30th day of readaptation period.

Figure 5. Results of thermal caloric test before and at end of 3rd hour of ANOH (-20°)

Conventional designations:

D--right labyrinth

S--left labyrinth

x-- $p < 0.05$

xx-- $p < 0.01$

Figure 6. Electronystagmogram (ENG) of caloric nystagmus of subject L-d, 25 years old, before and at end of 3rd hour of stay in ANOH (-20°)

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Upper curves: ENG during "thermal" calorizing of left and right labyrinth before ANOH

Lower curves: ENG during calorizing of right and left labyrinth at end of 3rd hour of stay in ANOH (-20°)

Figure 7. Electronystagmogram (ENG) of spontaneous nystagmus recorded in subject L-d, 25 years old, at 2nd hour 45th minute of stay in ANOH (-20°).

Upper curve: ENG in vertical plane

Lower curve: ENG in horizontal plane

Figure 8. Types of vestibular reactions in healthy individuals (n=50) under conditions of ANOH,