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CERTAIN ASPECTS OF THE VESTIBULAR PROBLEM IN SPACE MEDICINE

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16. Abstract Vestibulovegetative Disorders on manned space flights is discussed. A study relating to the vestibular stimuli in respiration, diaphoresis cardiac rhythm and a board complex of hemodynamic indices was conducted. Certain tests for astronaut candidates are discussed. Further investigations on the vestibular problem in space flight are deemed necessary.			
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CERTAIN ASPECTS OF THE VESTIBULAR PROBLEM IN
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MOSCOW, 1977 No. 10/77-1

Analysis of the medical provision on manned space flights shows that vestibulovegetative disorders developed in a number of cosmonauts and astronauts who had been in space. /1*

The degree of manifestation of the indicated disorders was highly variable--from slight discomfort, unpleasant feelings of heaviness in the stomach to nausea and vomiting. Individual symptoms of the motion sickness type appeared at various times (from the first minutes to the seventh day) and continued from three hours to several days. In all cases the development of these symptoms was linked to sudden movements of the head, especially in the first days of flight.

The pharmacological drugs tested under ground conditions did not always have a prophylactic and therapeutic effect in weightlessness.

As is known the vestibular problem in space medicine became especially acute after the flight of G. S. Titov. Since that time this problem has maintained its urgency even to the present time.

Despite the fact that many attempts were made to explain the genesis of vegetative disorders which occur under the influence of zero gravity there has yet been no generally acknowledged concept to explain their origin and mechanism of development. During the intensive research efforts on the vestibular problem

*Numbers in the margin indicate pagination in the original foreign text.

after the referred to G. S. Titov flight, the most applicable at that time were the concepts of K. L. Khilov which explained the development of vestibulovegetative disorders in space flight by the disappearance of the inhibiting effect of otoconia under conditions of weightlessness on the semicircular canals and by the increase in excitability and reactivity of the latter. /2

The viewpoint of M. D. Yemel'yanov, V. I. Kopanov and G. L. Komendantov was also imposed; it explained the mentioned disorders by the disruption in interaction of the afferent systems under the influence of zero gravity. Both viewpoints, as is known, were also shared by American authors. In particular the indicated considerations were reinforced by studies on the key importance of the sensory conflict in the manifestation of motion sickness (Steele, 1970; Reason, 1969).

The "vestibular nature" of vegetative disorders in space was stressed in the works of Graybiel, in whose opinion functional "deafferentation of otoconia" occurs in weightlessness. However, on the basis of findings in research on the vestibular function in members of the "Skylab" crew Graybiel perceives the possibility of motion sickness developing in zero gravity also as a result of paravestibular effects. The lack of a correlation between the prognostic tests which he made under ground conditions and during the "Skylab" space flight stresses the importance of the adaptive mechanisms in the human organism to weightlessness and the individual nature of this process.

This report does not propose to present an analytical survey of the genesis of vegetative disorders in zero gravity and a detailed discussion of all the currently existing hypotheses. It should merely be stressed that in the overwhelming majority these hypotheses acknowledge interest in a certain stage of the vestibular system.

After G. S. Titov's flight efforts were undertaken to develop measures to prevent the development of the space form of motion sickness in order to ensure a high degree of efficiency of the cosmonauts during the space flight. /3

Based on the viewpoints existing at that time on the "vestibular genesis" of the space form of motion sickness the approach was justified to the solution of this problem which relied on the experience of aviation and marine medicine and the basic research on this topic of the school of V. I. Voyachek.

The many years of experience of aviation and marine medicine indicated that the optimal solution for similar types of problems could be implemented by perfecting the vestibular selection of candidates for cosmonauts and creating a rational system of training.

However, it was already clear in that period that the space form of motion sickness nevertheless has its peculiarities both in symptomatology and in the mechanisms of development, therefore the formation of a system for selection and training of cosmonaut candidates could only use the general principles and approaches elaborated by the school of V. I. Voyachek. The methodological section required specific corrections, the introduction of methods for selection and training which could simulate the conditions and influence of space flight factors.

Taking into consideration the rather high selectivity in the reaction of the vestibular apparatus to various adequate stimuli, it was considered expedient in the selection of candidates to employ a set of them with consideration for the effect on different links in the vestibular apparatus and the systems interacting with it. At the same time it was shown that a fairly complete characteristic of the vestibulovegetative stability in man can be obtained by employing cumulative tests with the influence of rectilinear (rocking on swings) and Coriolis accelerations--(different modifications of the "CA test"), as well as by a combination of nonspecific factors (optokinetic stimuli in combination with 4 balancing on an unstable support). The technique for conducting these studies in the Soviet Union has been published in a number of works and has been previously sent to the US specialists.

In the development of techniques for stimulating the vestibular apparatus priority was given to tests in which the main stimulus was the so-called Coriolis accelerations which are created in revolving systems.

The initial position in the use of these stimuli was that circumstance that the vestibulovegetative disorders in space flight were always manifest in relation to head movements. A similar nature of reaction, as is known, can be obtained under the influence of Coriolis accelerations.

In the formulation of objective methods and criteria for evaluating the organism's reactions to the effect of vestibular stimulation it was revealed that in the interpretation of the findings the vestibulovegetative reflexes occupy a leading place. A study was made of the effect of the vestibular stimuli on respiration, diaphoresis, cardiac rhythm, a broad complex of hemodynamic indices, etc. Analysis of the numerous studies permitted one to note the great significance in the evaluation of the organism's reactions to vestibular stimulation of the integrative indices of hemodynamics (shock, momentary volume, peripheral resistance). Especial attention was directed not only to the extent of the elicited disorders, but also the duration of the restoration after a vestibular test was made, which could be used to evaluate the "pliability" of the regulatory mechanisms. Based on a study of the individual peculiarities of the vestibulovegetative reactions in the organism of candidates to a set of factors the candidates were differentiated according to the state of vestibulovegetative 15 stability.

For the delimiting of extreme types of endurance of vestibular factors very informative was the two-minute discontinuous test with the influence of Coriolis accelerations (DCA) or two-minute continuous influence (CDA). The experience of vestibulometric studies showed that individuals who did not endure the two-minute influence in 85% of the cases were not promising in so far as they are not inclined to be trainable. On the other hand, in this category of individuals the vegetative reactions are manifest not only in the form of nausea and vomiting, but also in drastic hemodynamic shifts all the way to precollapse states. The most complex was prediction for individuals with the so-called mean level of vestibular stability, i.e., individuals in whom the first vestibulometric investigation detected vegetative reactions of moderate and average pronounced nature by the end of the study, or for the 5-7 minutes of testing with influence of Coriolis acceleration. In these cases repeated vestibulometry with

evaluation of an extensive set of hemodynamic indices permitted determination of the direction of vestibulovegetative reactions and the trainability of the candidate, which was the basis for drawing a conclusion on the suitability of the entrant for the training stage, and further, after its completion--suitability for the space flight.

The experience of the medical provision of space flights permits one to note the fact that individuals who have, according to the data of ground vestibulometry, a high "initial" level of vestibular stability essentially do not have vestibulovegetative disorders in the space flight.

TABLE 1
MANIFESTATION OF SPACE FORM OF MOTION SICKNESS IN INDIVIDUALS
WITH A HIGH "INITIAL" LEVEL OF VESTIBULAR STABILITY
5 points

/6

Last name of cosmonauts	Initial level of VS	Training		VS before flight	VD in flight
		act.	pass.		
Nikolayev, A. G.	4-5	+	+	5	0
Bykovskiy, V. F.	5	+	+	5	0
Filipchenko, A. V.	5	+	+	5	0
Volkov, V. N.	4-5	+	+	5	0
Lazarev, V. G.	5	+	+	5	0
Rozhdestvenskiy, V. I.	5	+	+	5	0

Thus vestibular disorders were lacking in V. F. Bykovskiy who participated in 2 expeditions and who had innate high vestibular stability. Vestibular discomfort was not experienced by V. N. Volkov, A. G. Nikolayev, V. I. Rozhdestvenskiy, A. V. Filipchenko and V. G. Lazarev--cosmonauts with high indices of vestibulovegetative stability noted in the first selection. At the same time G. S. Titov, V. V. Tereshkova, B. B. Yegorov and K. P. Feoktistov noted vestibulovegetative disorder, or a varying degree of discomfort. According to the data of ground vestibulometry in the primary investigation they were not included in the category of individuals with a high level of vestibular stability (table 2).

Tables 1, 2, 3 and 4 present the data on the state of vestibular stability of cosmonauts according to the results of ground vestibulometry, the results of

ground training and the manifestation of vegetative disorders in flight (in points).

TABLE 2
MANIFESTATION OF SPACE FORM OF MOTION SICKNESS IN INDIVIDUALS WITH
LOW "INITIAL" LEVEL OF VESTIBULAR STABILITY

3 points

Last name of cosmonauts	Init.level of VS	Training		VS before flight	VD in flight	Notes
		act.	pass.			
Titov, G. S.	3	-	-	3	3	
Tereshkova, V. V.	3	+	-	3-4	3	
Feoktistov, K. P.	3	+	+	4	1-2	
Yegorov, B. B.	3	+	+	4	1-2	
Leonov, A. A.	3-4	+	+	4-5	0-1	
Beregovoy, G. T.	3-4	+	+	4	1	
Shonin, G. S.	3-4	+	+	4	0	
Kubasov, V. N.	3-4	+	+	4	0-1	
Artyukhin, Yu. P.	3	+	+	5	0	
Lebedev, V. V.	3	+	+	4	0-1	
Grechko, G. M.	3-4	+	+	4	0-1	

By the initial level is meant the vestibular stability of the cosmonaut which is revealed at the selection stage, i.e., before he enters the Training Center. The vestibular stability before flight is the results of control vestibulometry after the completion of the vestibular training cycle.

1-2 points--low stability (intolerability of two-minute influence of Coriolis acceleration)

3 points--low stability (tolerability of testing with influence of Coriolis accelerations 6-7 minutes, with phenomenon of VDI-II st.)

4 points--mean level of stability (tolerability of testing with influence of Coriolis accelerations to 10 minutes without VD)

5 points--high stability (tolerability of testing with influence of Coriolis acceleration over 10 minutes without VD)

TABLE 3

/8

MANIFESTATION OF SPACE FORM OF MOTION SICKNESS IN
INDIVIDUALS WITH MEAN LEVEL OF VESTIBULAR STABILITY
4 points

Last name of cosmonauts	Init. level of VS	Training		VS before flight	VD in flight	Notes
		act.	pass.			
Popovich, P. R.	4	+	+	4	1	
Komarov, V. M.	4	+	+	4-5	0	
Belyayev, P. I.	4	+	+	4-5	0	
Shatalov, V. A.	4	+	+	5	0	
Volynov, B. V.	4	+	+	5	0	
Yeleseyev, A. S.	4	±	+	5	0	
Khrynov, Ye. V.	4	±	+	5	0	
Gorbatko, V. V.	4	+	+	5	0	
Sevast'yanov, V. I.	4	+	+	4	0	
Rukovishnikov, N. N.	4	+	+	4	1	
Dobrovol'skiy, G. T.	4	+	+	5	0	
Patsayev, V. I.	4	+	+	4	0	
Makarov, O. G.	4	+	+	5	0-1	
Klimuk, P. I.	4	+	+	4	2-3	
Sarafanov, G. V.	4	+	+	4	0	
Demin, L. S.	4	+	+	4	0	
Gubarev, A. A.	4	±	+	4	0	
Molobov, V. M.	4	+	+	5	0	
Aksenov, V. V.	4	+	+	5	0	
Zudov, V. V.	4	+	+	4	0	
Glaskov, Yu. N.	4	+	+	5	0	
Kovalenok, V. V.	4	+	+	4	0	
Ryumin, V. V.	4	±	+	4	0	

Vegetative disorders (VD) occurring as a result of vestibular stimulation as in flight were evaluated according to the scale of V. I. Voyachek and K. L. Khilov, i.e., on a four-point scale:

0 degree--without vegetative reactions

I stage--slight discomfort

II-stage--symptoms of discomfort, some perspiration, salivation, slight paling

III stage--pronounced vegetative disorders, nausea, vomiting, acute palor, etc.

With the introduction of comprehensive vestibular training in the group of cosmonauts with a mean level of stability (initial level 4 point), in the majority of them, with the exception of P. I. Klimuk no pronounced vestibulo-vegetative disorders or symptoms of discomfort were observed which would have disrupted efficiency in flight.

The technique for conducting vestibular training with consideration for their comprehensive use has been published, while materials on this were previously sent to the United States at one of the meetings of the working group. /9

As is known, in recent years the attention of physiologists, clinic physicians and specialists in the area of sports medicine has been drawn to the problem of autotraining.

A number of American and Soviet laboratories are occupied with the formulation of the scientific bases and procedures for using the mechanisms of self-regulation of the vegetative functions in order to arrest and prevent even certain pathological conditions (paroxysmal tachycardia, epileptic attacks, etc.) and the reduction of physiological reactions under various stresses, including manifestations of motion sickness.

The principle basis for autogenous training is the teaching of the trainees to detect early manifestations--prodromes of developing disorders at stages when the process is still reversible and it can be arrested by engaging certain inhibitory mechanisms (diversion of attention, muscle strain, etc.). It is evident that the comprehensive vestibular training employed by us mobilizes the mechanisms of autotraining. By being exposed to numerous vestibular stimulations, experiencing slight manifestations of motion sickness again and again, the cosmonauts are trained to isolate and recognize its first prodromes, /10

to meet them "without panic" and to intelligently use certain measures available to them to arrest the developing process at early stages (limiting movement, stress of specific muscle groups, deep respiration, etc.). The validity of this conclusion is confirmed by observations made by a number of cosmonauts who passed vestibular training and who noted that the training not only increased their vestibular stability, but also prepared them psychologically and permitted them to develop the ability to control the vestibular load during movements and working operations in a real flight.

Apparently the use of the principles of self-regulation of the vegetative functions for the prevention and treatment of the space form of motion sickness should be considered justified.

By now one can already say more specifically that due to the ground vestibular training the cosmonauts have already begun to be well oriented in a situation of an acute period of adaptation. They do not drive themselves to a critical state by movements, sensibly control their motor activity in the first days of the flight, thus promoting the most rapid adaptation to weightlessness. They therefore have actually ceased to fear vestibular disorders, especially /11 cosmonauts who fly repeatedly. They know how to avoid unpleasant symptoms, what is the limit of their motor activity in the period of acute adaptation and they control it by their sensations. In addition to vestibular training the cosmonauts attach great importance also to training for redistribution of blood and, in particular, sleep with the foot end of the bed raised the last two weeks before the start.

Thus, it can be said that the experiment of Soviet space medicine on the use of the system of vestibular training of cosmonauts had favorable results.

However, this problem can still not be considered definitively solved in so far as the accumulation of factual data on the tolerability of space flights both by Soviet cosmonauts and US astronauts places new tasks before space medicine to perfect the system of training and to find new ways to solve them.

Despite the generally positive evaluation of the training results as previously indicated, nevertheless in individual cases symptoms of discomfort and even pronounced vestibulovegetative disorders in flight were found in individuals who had been subject to vestibular training, as indicated in tables 2 and 3 and even in table 4 which presents cosmonauts who flew again.

Up to now the question remains insufficiently clear as to why, despite the same conditions for the habitat in flight, vestibulovegetative disorders occur not in all the cosmonauts and astronauts, but only in some of them. This question, by the way, is also an urgent one for "ground" conditions, in particular for /12 aviation and marine medicine because an individual nature of reactions to vestibular stimulation is fairly often found among pilots and sailors.

TABLE 4
MANIFESTATION OF SPACE FORM OF MOTION SICKNESS IN COSMONAUTS
WHO REPEATEDLY MAKE FLIGHTS

Last name of cosmonauts	Init. level VS	Training		VS before flight	VD in flight	Notes
		act.	pass.			
Shatalov, V. A.	4	+	+	5	0	
Yelisseyev, A. S.	4	+	+	5	0	
Nikolayev, A. G.	5	+	+	5	0	
Sevost'yanov, V. I.	4	+	+	4	0	
Whatalov, V. A.	4	+	+	5	0	
Yelisseyev, A. S.	4	+	+	4	0	
Volkov, V. N.	4-5	+	+	5	0	
Popovich, P. R.	4	+	+	4	1	
Filipchenko, A. V.	5	+	+	5	0	
Rukovishnikov, N. N.	4	+	+	4	0-1	
Klimuk, P. I.	4	+	+	4	2	
Leonov, A. A.	3-4	+	+	4	1-2	
Kubasov, V. N.	3-4	+	+	4	0-1	
Volynov, B. V.	4	+	+	5	0	
Bykovskiy, V. F.	5	+	+	5	0	
Gorbatko, V. V.	4	+	+	5	0	

Regardless of which views are held on the mechanism of vestibulovegetative disorders in zero gravity, it remains obvious that the question on the reasons for individual differences needs to be answered.

Until recently the attention of researchers was mainly focused on the conditions for the functioning of the vestibular analyzer in weightlessness as an unusual habitat and on other exogenous factors. The endogenous factors were studied to a lesser degree, and especially those clinicophysiological peculiarities of the entire organism which could have a significant effect on the functional state of the vestibular analyzer or even overcome its resistance to motion sickness. /13

Among the numerous directions which can be planned in the solution of this task, the approaches are completely justified which pursue the goal of determining the role of the initial state of the vestibular system, the cardiovascular system and the vegetative-humoral sphere in respect to the human predisposition to motion sickness.

The hypothesis that the nature of the nystagmus must contain information on the level of vestibular stability is not new. Published data on this question are highly contradictory. In the studies, the results of which are presented further, a comparison was made of electronystagmograms (ENG) obtained by single angular accelerations $+15 \text{ deg/sec}^2$ (duration 6 sec) and -90 deg/sec^2 (duration 1 sec) in individuals with a varying level of vestibular stability (LVS). Healthy males ages 20-40 were examined. The level of vestibular stability was evaluated according to the tolerability for a standard test with discontinuous influence of Coriolis accelerations (DCA). The results of the studies showed that:

- 1) the intensity of nystagmus is lower the higher the LVS;
- 2) the stop-stimulus is a more informative testing stimulus than the positive angular acceleration;
- 3) the greatest differences in the ENG parameters between groups of individuals with a different LVS are [illegible] according to the rate of the slow component (RSC) and the rate of the fast component (RFC) of nystagmus. /14

The technique of statistical solutions was used to study the prognostic importance.

It should nevertheless be noted that the prognostic significance of the nystagmography method is not great and it can hardly replace the available traditional tests. However, as a supplemental procedure in the set of other methods nystagmography can be useful especially in the variant with stop-stimulus, keeping in mind its comparatively small stress influence. In addition, it should be stressed that according to the dynamics of the nystagmus reaction, if it is traced in the process of vestibular training, one can obtain fairly objective information on its efficacy. Incidentally, this is confirmed by many authors.

Significant changes in the hemodynamics during rocking have been revealed by many authors and are viewed as one of the essential factors in the pathogenesis of motion sickness. Therefore the hypothesis on the role of the initial functional state of the cardiovascular system in relation to the degree of human predisposition to motion sickness is fairly valid.

In particular, B. I. Polyakov and coauthors (1977) made a study on the possibility of predicting resistance to motion sickness from the results of the tolerability for an orthostatic test. At the same time the peculiarities of transitional processes were studied in the cardiovascular system in response to redistribution of blood during orthostatism (by the nature of the dynamic changes in cardiointervalograms, rheovasograms and rheoencephalograms).

A number of mathematical models were obtained for the studied indices. The greatest prognostic value was possessed by that model whose structure included both indices of cardiac activity and characteristics for the change in vascular tension. /15

$$y = -52,8 - 19,9X_2 + 32,4X_4 - 370IX_5 - 42IX_3 - 67,7X_{II} + 195X_{I2} - 0,763X_{I3}, \quad (1)$$

where X_2 -- index for the extent of the transitional process according to cardio-intervalogram;

X_4 -- mean amount of RR in lying down position, in sec.;

X_5 -- dispersion of interval RR in clinostatic position;

- X_6 --error in mean value RR in clinostatic position;
 X_{11} --electrical resistance of leg tissue in clinostatic position;
 X_{12} -- the same in orthostatic position;
 X_{13} --change in parameter X_{12} in relation to parameter X_{11} (in %).

The study results permit the opinion to be stated that the degree of coordination in the reactions of the heart and vessels in response to the orthostatic influence is an important prognostic sign in relation to tolerability for vestibular factors.

The humoral-hormonal mechanisms for regulating the function during motion sickness are being investigated. The materials from this direction of research indicate the presence of significant and diverse changes in the exchange of biologically active substances (metabolites, mediators, hormones) with stimulation of the vestibular apparatus. The question of the state of vegetative-humoral-hormonal complex in individuals with a varying level of vestibular stability and the role of the humoral-hormonal factors in the human predisposition to motion sickness has been treated to a lesser extent. The results of this direction indicate that for individuals prone to motion sickness the dominance of tropho- /16
tropic mechanisms is characteristic, in particular, a relatively lower activity in the sympathoadrenal system, relatively higher activity in the systems of histamine and serotonin. On the other hand, for individuals highly resistant to motion sickness the dominance of ergotropic mechanisms is characteristic, in particular, relatively higher activity of the sympathoadrenal system and lower activity of the system of histamine and serotonin. This group is characterized by a pronounced ability for acetylcholine inactivation. An attempt was made to obtain a mathematical model to predict the level of vestibular stability of a man according to the initial content in the blood of biologically active substances.

$$y = -21,58 - 3I_1 + 28K_1 + 3,22K_2 + 0,707K_3 + 27,3K_4 + 148,58K_5 \quad (2)$$

where K_1 --the content in blood of free acetylcholine (mcg%);

K_2 --the amount of the ratio:

$$\frac{\text{free acetylcholine}}{\text{acetylcholine bound by erythrocytes}}$$

K_3 -- the amount of the ratio:

$$\frac{\text{activity of acetylcholinesterase}}{\text{free acetylcholine}}$$

K_4 --content in blood of primary acetylcholine (mcg%);

K_5 --content in blood of histamine (mcg/ml).

A study of the role of the initial status of various organs and systems in the tolerability of the human organism for stress influences is very promising, especially in the solution of the tasks of professional selection, prevention and treatment of the space form of motion sickness. This information, apparently, can be highly useful also in the study of the mechanisms for individual differences in the reactions of the human organism to the effect of space flight factors.

Analysis of the results of tolerability for space flights showed that in the /17 symptomatology of vestibulovegetative disorders a significant place is occupied by hemodynamic shifts. In the picture of developing symptoms of discomfort all the cosmonauts clearly traced the syndrome of blood rushing to the head with the sensation of a feeling of heaviness, and in a number of cases, with headaches, stuffiness of the nose, ears, puffiness of the face. Certain cosmonauts also indicated a sensation of "fullness or bulging in the area of the rib cage". All of this can be the cause of the overall discomfort of the cosmonaut, especially in that period when the development of "vestibular symptoms" is also expected (I. I. Bryanov and coauthors).

The importance of the hemodynamic component related to the redistribution of liquid media in the organism by now has become the subject of an intent study in model ground experiments.

Ground experiments with hypokinesia and, especially, with the so-called antiorthostatic hypokinesia revealed that redistribution of liquid media in a cranial direction elicits a number of shifts in the organism, and primarily, in the system of cerebral, pulmonary circulation, in the work and hemodynamics of the heart itself, in the interaction of the analyzers, water-salt exchange and so forth (M. P. Kus'min and coauthors, I. Ya. Yakovleva and coauthors, Kh. Kh. Yarullin and coauthors, et al.).

Sensitive endings embedded in the actual heart and membranes, as well as the intrathoracic sections of vessels in the greater and lesser circles of circulation related to it cannot remain indifferent to such a redistribution of blood. The changes which thus develop in the afferent pulsing to the cerebrum and spinal cord elicit not only pronounced reflector reactions in different homeostatic systems (V. V. Parin, V. N. Chernigovskiy, O. Gauer) but also significantly affect the state of the central nervous system (B. S. Kulayev). /18

Until recently the role of the hemodynamic component in the development of vestibulovegetative reactions under the influence of weightlessness was given little importance. However, the anatomical and physiological peculiarities of different levels in the vestibular system do not permit the idea that the vestibular analyzer can remain indifferent to the redistribution of liquid media in the organism and primarily of venous blood under conditions of zero gravity. There are sufficient grounds to assume that in weightlessness together with the development of a sensory conflict (meaning the discrepancy in the "calibrated" for ground conditions accompanying activity of the vestibular, optic, proprioceptive systems and interoception, disorder in interaction of otoconium and cupula apparatus) a new factor is connected which creates a unique background which is predisposed for the development of a vestibular crisis. This additional factor is hemodynamic disorders governed by the redistribution of blood in weightlessness. First of all, the venous plethora in the system of cerebral circulation can be a direct cause of the development of a disorder in spinal fluid and endolymphatic hemodynamics. According to anatomical and physiological data, confirmed by clinical materials, the most distinct changes in the spinal fluid and endolymphatic hemodynamics with the development of disorders in the vestibular analyzer are noted in the case of hemodynamic disorders in the basin of the vertebral and basilar arteries.

The significance of a venous stasis in the functioning of the vestibular analyzer is determined by the peculiarity of intracranial hemodynamics, characterized by the fact that the venous system occupies a considerably greater area than the arterial, and consequently, the difficulty of venous blood flowing off into the sinuses must result and does result in an increase in intracranial pressure, deceleration in blood flow, and consequently, a disruption of the /19

oxidizing processes and to an extremely pronounced degree--even in symptoms of anoxia. Incidentally, these processes were traced and studied well in the clinic for nervous diseases in the treatment of so-called venous insults. It is true that under conditions of zero gravity or in model experiments (antiorthostatic hypokinesia), apparently, the situation does not result in similar extreme degrees of changes. At the same time the data of experiments indicate that the statistically meaningful changes in the indices of the acid-alkali equilibrium of the human venous blood in antiorthostatic hypokinesia were found only in the blood flowing off from the brain (V. Ye. Katkov et al., 1977). The greatest changes affected the buffer capacity of the blood with a certain drop in pH. At the same time, in the blood flowing off from other organs as well as in the mixed venous blood only a tendency was found towards similar changes.

In this respect it should be stated that even moderate changes in the chemism of the cerebral blood flow, in the same way as the change in pressure in various liquid cerebral media, affect, as is known, the activity of the sensitive nerve formations embedded in the brain itself and its membranes. In the first place one should bear in mind the by now well-studied medullar chemoreceptors (see I. S. Breslav, 1973) and the hard cerebral membrane (M. A. Baron, 1947, V. N. Chernigovskiy, 1960, et al.).

For the mutual link in the function of the vestibular apparatus and the hemodynamics of the brain it is also appropriate to cite the results of clinical observations of otoneurologists (N. S. Blagoveshchenskaya, 1977) which show that in itself the change in hemodynamics of the brain of a functional nature results in a change in the state of the vestibular analyzer, which in turn elicits already secondary changes in cerebral hemodynamics. Thus, a unique vicious circle is created which exacerbates the condition of the analyzer. /20

From clinical data it is also known that the development of an imbalance in the spinal fluid system of the cerebrum, together with a headache, can be manifest in the form of vestibul sensory and vestibulovegetative crises as a result of the generalized irritation of the truncal and cortical structures of the cerebrum.

In light of the numerous studies on the pathogenesis and mechanism for development of vestibulopathy and Meniere-like states a specific place is occupied by information on the role of a disruption in the water-salt exchange (Johnson, 1973, Tsimmerman, 1952, Aubry, 1957), as well as the data on the imbalance in ions of potassium and calcium in the endolymph which occurs during a vestibular crisis (Johnson, 1973).

All of this acquires especial interest in so far as precisely the disruptions in water-salt balance, exchange of ions of potassium and calcium at the tissue level, as is known, occupy a leading place in the adaptive mechanisms of the human organism for zero gravity.

Thus, there are all the bases to assume that a disruption in the hemodynamics with specific microcirculatory disorders at the tissue and intercellular level, disruptions in the water-salt exchange with a tissue imbalance of ions of potassium and calcium, hypertensive direction of shifts in the spinal fluid-endolymphatic system create conditions predisposed towards the development of vestibulovegetative disorders in weightlessness according to the type of vestibular crises. .

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Analysis of the research results from model experiments revealed that in antiorthostatic hypokinesia in a definite number of individuals there are pronounced changes in the functional state of the vestibular analyzer and interacting systems, especially clearly determined in the period of acute adaptation to the new conditions of the influence of the gravity factor (1-10 days of the experiment).

Some of the subjects in the 1-3 days of the so-called antiorthostatic hypokinesia (-4° , -6° , -12°) experienced slight vertigo and nausea during drastic head turns and turning the eyes to extreme positions. In them in the first two days of the bed pattern electrographically nystagmoid movements were detected. The majority of the subjects noted the appearance of a different type of illusion "slight swinging", "upside-down body position", a feeling of "collapse", especially pronounced with closed eyes. Sometimes when the gaze was fixed on a single, immobile point in several seconds it seemed that it moved (autokinetic illusion)

(I. Ya. Yakovleva and coauthors).

Study of the accuracy of perception of coordinates of flat space in the first days of antiorthostatic hypokinesia revealed an increase in error 2-2.5 times in comparison with the norm.

Three types of reactions were found in the calorization of the labyrinth:

--differing slightly from the initial state;

--hyperreflexion according to nystagmus;

--tendency towards hyporeflexion according to nystagmus with increase in sensory and vegetative reaction.

It should be stressed that a similar differentiation into three types of /22 reaction of the vestibular analyzer in the calorization of the labyrinth was also during the occlusion tests with the creation of venous plethora in the head vessels. The observed reactions of the third type should be included in the generalized, with the participation of all links in the vestibular analyzer (receptor, truncal and cortical formations). It should be stressed that in this category of individuals after hypokinesia disruptions were recorded in the function of the postural equilibrium and vestibulovegetative stability which were more significant and lasting.

One should especially dwell on the case where under conditions of lengthy antiorthostatic hypokinesia on the background of the overall good condition in one of the observed individuals symptoms of a crisis developed with vestibulovegetative symptomatology which were evaluated as a result of the dynamic disruption in circulation on the level of the cerebral trunk. In a neurological examination the corresponding focal symptomatology was revealed. The symptomatology was very similar to the manifestation of the space form of motion sickness. In the patient with turning of the head nausea developed and the general state of health drastically deteriorated. These symptoms lasted several days, and then gradually passed.

Some researchers discovered symptoms of labyrinth irritation (spontaneous

mystagmus, vertigo, nausea) also in redistribution of blood occurring when negative pressure was suddenly removed from the lower half of the body (E. V. Lopayev and coauthors, 1975).

The conducted series of experiments which studied the influence on the cerebral circulation of antiorthostatic positions with ophthalmological control of the fundus oculi permitted the detection in some of the subjects of distinct signs of an increase in intracranial pressure characterized by the symptom of congestion in the papilla of the optic nerve and extreme plethora in the venous network.

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All of the aforementioned studies which were conducted with simulation under earth conditions of certain effects of zero gravity confirm the aforementioned hypothesis on the specific effect of redistribution of blood and liquid media in the organism which are inherent to weightlessness on the functional state of the vestibular analyzer and the systems interacting with it, as well as the possibility of pronounced individual reactions of the organism to the action of this additional factor.

By now a large amount of factual and experimental material has been accumulated which convincingly indicates that the human antiorthostatic position to a great extent simulates the effects which are noted in cosmonauts in the initial period of adaptation to weightlessness.

In this respect in the practice of space medicine it has begun to be considered expedient to use a functional-load test which permits analysis of the peculiarities of individual reactions of the organism to the action of an antiorthostatic position. In the pre- and post-flight examinations the antiorthostatic load is the second section of the passive postural test and consists of two series of successive inclinations of the subjects by 15° and 30° from the horizontal upside down for six minutes in each position with recording of the hemodynamics and gas exchange.

In the evaluation of the reaction of the cardiorespiratory system great attention was paid to the state of the systemic and regional circulation, in

particular, the filling with blood of various basins in the cerebrum, which was judged, in particular, by the change in rheoencephalographic indices in the bitemporal, bimastral and frontomastoidal leads. /24

Investigation of the organism's reactions to "antiorthostasis" before a space flight and after its completion permitted observation of the individual nature of the change in the studied indices and the varying pronounced nature of the compensatory and adaptive reactions. Thus, before the flight, in the captain of the "Soyuz-13" craft, P. Klimuk, during the antiorthostatic test a marked increase in blood accumulation in the vessels was recorded in the cerebrum in vertebrobasilar system with slight increase in pulse blood filling in the basin of the internal carotid artery, while at the same time in cosmonaut V. Lebedev a preeminent (roughly two-fold) rise was observed in the pulse blood filling in the system of the internal carotid artery with its small increase in the vertebrobasilar system. As is known, in P. I. Klimuk, in contrast to V. Lebedev, during the space flight pronounced vegetative reactions were observed. Further observations will show how natural this fact is.

The possibility is not excluded that the data of a comparative study of individual reactions in the basin of the internal carotid artery and the vertebrobasilar system to antiorthostasis can acquire definite meaning for predicting the nature of the hemodynamic shifts in these vascular basins in flight, in particular, in the initial period of the organism's adaptation to zero gravity.

At the same time, it should be noted that recently certain researchers have obtained data indicating that in itself the antiorthostatic action essentially does not alter the human sensitivity to motion sickness. In particular, such facts were obtained in the experiments of Graybiel and our co-workers. /25

In respect to these, seemingly contradictory facts, it can be said that first, in itself the tolerability of "antiorthostasis" as numerous ground experiments showed, is fairly individual, second, for the development of "unfavorable sleep", which could affect the functional state of the vestibular apparatus in the antiorthostatic position it is necessary to have a specific time

which is also highly individualized, and finally, the size of the angle of inclination is also of great importance. All of these conditions can significantly affect the research results. Incidentally, Graybiel also focused attention on some of them.

Thus, one can conclude that motion sickness in weightlessness is apparently determined by a collection of the aforementioned factors. Disorders in hemodynamics should be assigned the role of the factor which significantly affects the conditions of adaptation of the vestibular analyzer to zero gravity, predisposing to the development of decompensation and even a disruption in adaptation with manifestation of disorders of the vestibular crisis type.

The noted hemodynamic shifts which were given a lot of attention in this report, in themselves elicit essential changes in the activity of the interoceptive analyzer, and consequently, also the state of the central nervous system. This is stressed by the fact that in the pathogenesis of the space form of motion sickness, together with the vestibular mechanisms, as well as changes in the activity of the optic and proprioceptive analyzers a significant role is played /26 by the reconstruction of the afferent signaling from the receptors of the cerebrum and the organs of the rib cage. This also complicates the mechanisms for the emergence of a sensory conflict in weightlessness which affects the development of the examined disorders in the vegetative sphere during acute adaptation.

Consequently, the concept on the effect of the hemodynamic factors on the genesis of vegetative disorders in space flight supplements the known hypotheses on the effect of zero gravity on the vestibular analyzer, despite the fact that its initial premises were based primarily on extralabyrinth factors.

At the same time, from these positions it is possible to explain in a somewhat different aspect certain pathophysiological mechanisms of the vestibulo-vegetative disorders observed in space, to understand a number of peculiarities in the manifestation and development of this syndrome, also to interpret individual facts explaining, in particular, the individual nature of the human

organism's reaction to weightlessness, to state a number of considerations for the prevention and treatment of the space form of motion sickness, and finally, to make certain recommendations on the training of cosmonauts for space flights.

Thus, on the basis of the aforementioned considerations on the importance of the hemodynamic component in the genesis of the space form of motion sickness one can explain the fact of the emergence of vestibulovegetative disorders in weightlessness in certain cosmonauts with a high level of stability achieved by means of ground training. The possibility is not excluded that this category of individuals can possess a reduced adaptive capability to the redistribution of blood, in particular, with the development of dystonic symptoms in the system of vertebro-basilar arteries. It is natural that in these individuals with greater probability one should expect the development in flight also of unfavorable hemodynamic disorders, in particular, more pronounced congestion symptoms in the system of the cerebral circulation, and consequently, the creation of conditions for a breakdown in adaptation and manifestation of a crisis. Thus, poor adaptation or reduced adaptation to blood redistribution intensifies the predisposition to the space form of motion sickness. /27

On this basis it is completely correct to make recommendations (applicable to the tasks of selection and training) on the need for introducing tests to evaluate the nature of the human organism's reactions to factors of antiorthostatic positions which vary in strength, and at the training stages one can raise the question of using antiorthostatic tests to train the organism for blood redistribution.

The aforementioned does not belittle the importance of vestibular training for cosmonauts and the vestibulometric selection for candidates, in so far as the trainability of the vestibular analyzer and especially the "innate" resistance to "vestibular stress" undoubtedly inhibits the development of adverse reactions under the influence of weightlessness. The experience of space flights in the "Soyuz" program revealed that individuals with high vestibular stability have a higher hemodynamic stability in vestibular stimulation, and as already stated, they have a better tolerance for the influence of flight factors and adapt more

easily to them.

As is known, one of the arguments of the representatives of the vestibular genesis of the disorders observed in zero gravity is the claim that the vestibulovegetative disorders are manifest by the movement of the head, in so far as this implements an effect on the vestibular apparatus. This circumstance, as is known, was also the focus of attention of the American astronauts in those space programs in which work was planned on stations with a large volume. In the transition from the transport ship to the station there was a noticeable increase in the cases of development of vestibulovegetative disorders. /28

It can be agreed that actually the transfer of crew members from the craft with smaller volume to the compartment with large volume increases the possibility of head movements, as well as the production of additional irritations of the vestibular apparatus due to accelerations occurring in free movement. However, it should also be kept in mind that the movement of the crew members in the compartment of large volume entails an incommensurably great need for movement of the extremities. There is no need to prove that movement of the extremities and muscle contraction are the primary mechanism for the movement of venous blood to the right heart. Under conditions of zero gravity, high motor activity, especially of the extremities, will essentially exacerbate the situation of blood redistribution by accelerating the flow of blood from the distal sections of the extremities and at the same time intensifying the blocking of the outflow of venous blood from the head, and consequently promoting the most rapid development of hemodynamic disorders. From here certain considerations suggest themselves which refer to the prevention and treatment of the space form of motion sickness. First of all it is appropriate to make a certain reappraisal of the traditional drugs of the scopolamine order which have, as is known, the highest protective action against rocking. The use of these preparations in space flight for vestibulovegetative disorders may not give the desired effect.

The action of scopolamine, as is known, is directed towards blocking the central and peripheral M-cholinoreceptors, therefore in the given situation its effect on the development of vestibular symptoms is not complete, since it /29

is not directed towards the elimination of other reasons for the disorders. In this respect it is promising to combine préparations of the scopolamine order and drugs which reduce labyrinthine hydrops. However, it should be kept in mind that extreme dehydration of the organism under conditions of weightlessness can have an undesirable consequence for the organism as a whole. In this plan it is appropriate to recall sodium hydrocarbonate. Clinical observations made in the Soviet Union (I. I. Potanov, V. N. Barnadskiy, 1973) on patients with Meniere-like diseases and by vestibulometry revealed the fairly high efficacy of bicarbonate as a medicine. The authors showed that the action of bicarbonate in the given group of patients was directed towards normalization of the water-salt exchange, the content of potassium ions in the tissues and an increase in the alkali reserve. The action of this preparation on the human organism in model experiments and the elaboration of a technique for using it in space flight can become the subject of a special study in the near future.

In the plan for discussing the question of the treatment and prevention of vestibular symptoms in space flight it is expedient to state certain considerations on the proposal of a number of authors who recommend the use of a set of measured head movements in order to accelerate the adaptation process of the vestibular system to zero gravity. Apparently, this means of action must be used extremely carefully with consideration for the passage of overall adaptation of the organism to the hemodynamic shifts and individual peculiarities in the manifestation of vestibulovegetative reactions. One should especially dwell on tests with the action of negative pressure on the lower half of the body (NPLB), as well as tests with occlusion rings on the lower extremities. /30

The use of these tests can undoubtedly have a positive effect and possibly even arrest negative disorders. It should be stressed however that preference must still be given to the test with occlusion rings on the thighs having in mind the use of them as treatment-preventative measures. Occlusion rings may not only inhibit the process of blood redistribution by depositing it in the lower extremities, but also create specific pressure in the venous system of the lower extremities, as though preserving the "lost" gravitational effect. The advantage of the occlusion rings is also that their application will not disrupt

the professional activity of the cosmonaut and they are simple to use. Moreover, the process of controlling pressure in the occlusion rings can generally be automated.

However, it should be stated that tests with occlusion rings as treatment-preventative measures directed against extreme hemodynamic shifts in weightlessness still require verification in model experiments and approbation under conditions of a real flight.

Of course the stated aspects do not exhaust the vestibular problem in space medicine. Most likely other approaches can be proposed for the solution of the problem of the selection and training of cosmonauts. In particular, attention should be drawn to the proposal on the use of autogenous training directed towards self-regulation of the vegetative functions, including of the cardiovascular system.

It goes without saying that the vestibular problem needs further elaboration with the use of the possibility of conducting studies in space and model ground experiments.

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