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MONOGRAPHS ON SPACE PHYSIOLOGY

by

V. V. Parin, R. M. Bayevskiy, et al.

FOREIGN TECHNOLOGY DIVISION

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MONOGRAPHS ON SPACE PHYSIOLOGY

By: V. V. Parin, R. M. Bayevskiy, et al.

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Space physiology is a new scientific direction, intimately connected with the practice of the medico-biological preservation of the safety of space flights. A separate chapter is dedicated to the methods of physiological investigations in flight. It points out the broad use of biotelemetry for transmitting data about the state of the astronaut from on board the ship to earth. A number of specific methods developed for registering physiological functions in flight is described. Numerous data obtained in the performance of flying experiments with animals and and during space flights of man are examined in the light of the existing theoretical concepts about regulation of functions in the living organism. Moreover, both the classical ideas as well as the new conceptions connected with ideas of cybernetics are employed. In this book much space is allotted to the problem of vestibulo-vegitative reactions, the motion-sickness syndrome. It is shown that these phenomena must be examined as an overall reaction of the organism, caused by the disturbance of the interconnection of the afferent systems. In the concluding chapter the prospects are examined for the development of space physiology, included in which are problems of lunar and interplanetary flights, problems of biocontrol and of the further developemant of the methods of investigation.

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

* <u>ye</u> initially, after vowels, and after ъ, ь; <u>e</u> elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

FOLLOWING ARE THE CORRESPONDING RUSSIAN AND ENGLISH DESIGNATIONS OF THE TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	sech^{-1}
arc csch	csch^{-1}
rot	curl
lg	log

ANNOTATION

Space physiology — one of the divisions of space biology and medicine, which deals with the study of the reaction of the organism and its systems to the influence of the extreme factors of space flight. In these monographs there are illuminated several of the most urgent problems of space physiology.

Space physiology is a new scientific direction, intimately connected with the practice of the medico-biological preservation of the safety of space flights. A separate chapter is dedicated to the methods of physiological investigations in flight. It points out the broad use of biotelemetry for transmitting data about the state of the astronaut from on board the ship to earth. A number of specific methods developed for registering physiological functions in flight is described.

Numerous data obtained in the performance of flying experiments with animals and during space flights of man are examined in the light of the existing theoretical concepts about the regulation of functions in the living organism. Moreover, both the classical ideas as well as the new conceptions connected with ideas of cybernetics are employed.

In this book much space is allotted to the problem of vestibulo-vegetative reactions, the motion-sickness syndrome. It is shown that these phenomena must be examined as an overall reaction of the organism, caused by the disturbance of the interconnection of the afferent systems. Moreover, great importance is attached to the extralabyrinthine reactions.

The question of the effect of factors of space flight on the digestive system was subjected to special consideration. It is shown that this system can be an important indicator of the reactions of the entire organism to extreme effects of special importance is the study of the functions of the neuroglandular apparatus of the digestive system in connection with the results of after-effect.

In the concluding chapter the prospects are examined for the development of space physiology, included in which are problems of lunar and interplanetary flights, problems of biocontrol [Translator's Note: biocontrol could be life monitoring.] and of the further development of the methods of investigation.

The book includes a literature index containing 399 works of Soviet and foreign authors. Also in the book are 42 figures and 5 tables.

PREFACE

The development of space biology and medicine led to the formation of a number of new scientific directions and disciplines. There appeared space psychology, space microbiology, space physiology, etc. These disciplines at present in a number of cases do not have clear borders and their interrelationship is sometimes more prominent than their internal structure. Moreover, individual divisions of such new directions develop more intensively by force of the pressing requirements of practice than others.

In this book an attempt is made to examine certain problems of space physiology — both those that are already well studied, as well as those still in the stages of formulation and primary discussion. In individual chapters there are presented data obtained in space flights and as a result of experimental, laboratory investigations. Even a random account of special questions shows, how much has been done by Soviet science in the area of the conquest of outer space during a very short period. A base has been created for the further development the new science — space physiology. A great number of facts has been gathered, which are necessary for comprehending the principles of the functioning of the living organism under the new (for it) conditions of existence. Now, in a period, when the whole nation is getting ready to celebrate the 50th anniversary of the October Revolution, we can note with pride that among the numerous successes of Soviet science there are also achievements, which are especially important for ensuring future, even more prolonged and remote, flights of man into space.

The development of new methods of investigation, which are suitable for the conditions of flight experimentation, was one of the first problems of space biology and medicine. The necessity to record physiological indices of man and animals, located at a great distance from the researcher-physician, led to the broad development of the technology of remote biological measurements — biological telemetry. At present biotelemetry is a basic method of the physiological investigations and medical monitoring under the conditions of space flight.

The study of influence of the factors of space flight on the organism pertains to the number of basic problems of space physiology. In this book there are examined certain mechanisms of physiological reactions in flight. An attempt has been made to use the concepts of cybernetics for the interpretation of a number of already described facts. A hypothesis is proposed about the fact that during extreme influences there occurs a reorganization of the lowest levels of regulation (vegetative) in a direction necessary to ensure the optimum functioning of the higher levels of regulation, in particular of the cerebral cortex.

In recent years in space medicine much attention has been devoted to the problem of vestibulo-vegetative disorders. At present it has become clear that the symptoms detected in certain astronauts, which are similar to the motion sickness syndrome, must not be examined as an isolated disturbance of the functions of the vestibular apparatus. These disturbances, apparently, are a general reaction of the organism caused by changes of the interrelationship of afferent systems and the difficulty of interaction of different levels of regulation.

The idea, that the observed functional changes of different systems and organs are short-term and transitory, is based on the results of a study of physiological systems possessing great mobility and very short transition processes. The effects of the accumulation of stimulations during the study of these systems are frequently levelled by current reactions. Therefore, of great interest are the data about the digestive system and about certain morphologic changes in tissues, illustrating the ability of the organism in prolonged preservation of the traces of stimulation.

Finally, in this book there are examined the prospects of the development of space physiology, which include problems of lunar and interplanetary flights, problems of biocontrol (life-systems monitoring) and the minimizing of vital functions, and questions of the development of methods of investigation in space. Naturally, the variety and versatility of the problems of space physiology are not nearly exhausted by the materials presented in this work. But the data presented in this book rather convincingly emphasized the uniqueness of space physiology as a new, scientific direction, in which theoretical research is profoundly and intimately interlaced with the carrying out of space flights, with the ensuring of their safety and with the development of prophylactic measures.

CHAPTER I

SPACE PHYSIOLOGY AS A NEW SCIENTIFIC DIRECTION

The progress of rocket technology and the birth of astronautics demanded the development of a large complex of scientific directions and led to the appearance of a whole series new disciplines.

In the field of natural sciences there were formed space biology and medicine, the problems of which are connected both with the ensuring of optimum conditions of vital activity of man in outer space, as well as with the investigations of the influence of the factors of flight on the living organism and with the study of forms of extraterrestrial life. The great variety of problems and questions of space biology and medicine demanded a profiling of the investigations, their clear differentiation during a condition of simultaneous grouping of different directions. Such grouping is necessary for practical safeguarding of the ground and flying experiments, the solution of questions of astronaut training and several other problems.

As is known, one of the most important divisions of space biology and medicine is space physiology — the science of the functional characteristics of a living organism during action of the factors of space flight.

It is possible to distinguish three groups of factors, which can effect the human organism or an animal in space flight:

1) factors characterizing outer space as a unique environment for inhabitation (ionizing radiation; meteorites and vacuum);

2) factors connected with the dynamics of flight (weightlessness, acceleration, vibration);

3) factors caused by a prolonged stay in the artificial environment of pressurized cabins with small volume (isolation, adynomia, emotional stress and the peculiarities of the microclimate).

Almost all the enumerated factors, except prolonged weightlessness and, in particular, ionizing radiation (by its energy spectrum), can be reproduced under laboratory conditions, which determines the possibility of an appropriate organization of investigations for animals or man. However, the laboratory experiments are only preparatory and preliminary. The main method of space physiology – experimentation in flight. Only in such experimentation can the overall influence of the many factors in their actual and temporary sequence and their interconnection be reproduced.

Space physiology studies the influence of extreme effects on the functional state of individual systems of the organism and on the organism as a whole. However, researchers usually distinguish subdivisions of physiology, connected with the study of the influence of any of these factors (for example, the physiology of the effect of accelerations, the physiology of decompression disorders,etc.). A similar tendency has already led to essential gaps in the study of the reaction of the entire organism to the effects of both individual factors and especially to groups of factors. For example, in studying the effect of accelerations little attention has been focussed on the state of the digestive apparatus and the excretory system. During the study of the effect of emotional stresses almost no attention has been allotted to the reactions of the circulatory and respiratory systems.

The problems of life-support and the investigation of the adaptive reactions of the living organism under conditions of flight place the study of vegetative functions in one of the most prominent positions. The first flying experiments with animals, starting with the flight of the dog Layka, were connected with the problem of survival, i.e., with the solution of the problem of maintaining the basic vital functions of the animal at a level compatible with life. Space physiology on the whole has tremendous importance in the matter of ensuring the safety of manned flight. All the diagnostic tests are based primarily on the evaluation of pulse and respiration — the basic physiological indices. The further extension of our concepts about the state of the vegetative functions under extreme effects will make it possible to considerably increase the effectiveness of the medical monitoring of the state of the astronauts in flight.

Manned flight is connected with the performance of specific, critical assignments, i.e., it makes great demands on the neuromuscular system of man. The intake of food, and the start-stop operation of a transceiver require specific energy expenditures and motor coordination. More complex operations, such as the orientation of the ship, photographing in space, the performance of scientific investigations, are connected with the complex interaction of the afferent and efferent systems and with the processing of information and they can occur otherwise than they do on earth. In solving these questions the role of investigations in the field of the physiology of analyzers is very great.

Finally, the inquiry into the nature of the observed changes on the basis of an overall appraisal of the state of all levels of the organism, starting with the subcellular and ending with the cortical, also enters into the problem of space physiology and is investigated with by the broad application of cybernetic methods. However, the value of cybernetics in space physiology is not particularly exhausted by the physiological problems. To it belongs a conspicuous role in questions of prognostication, the organization of experiments, the development of methods for obtaining physiological information under conditions of flight experiments and in the application of methods for analyzing this information.

Being a part of space medicine, space physiology is historically connected with aeromedicine and aviation physiology. The physiological investigations carried out in the preparation for and the realization of flights of Soviet stratonauts [balloonists] at the beginning of the 30's, are in a certain sense a transitional stage between aviation and space physiology.

The works of L. A. Orbeli [169], A. V. Lebedinskiy [137], N. N. Sirotinin [218], V. A. Spasskiy [221], I. P. Razenkov [204], M. P. Brestkin [49], D. Ye. Rozenblyum [210], A. P. Popov [197], V. V. Strel'tsov [223], M. Ye. Marshak [152], A. P. Apollonov [12], V. G. Mirolyubov [158], N. M. Dobrotvorskiy [86] and others played a great role in discovering the mechanisms of function regulation under conditions of the effect on the organism of certain extraordinary in intensity factors of flight (hypoxia, acceleration, increased and decreased barometric pressure, radiation, rapid decompression and others). The investigations of these scientists contributed to the creation of the means for medically safeguarding flights — pressurized cabins, oxygen-respiratory equipment, pressure suits, etc. The results of numerous, complex high-altitude expeditions in the Altay and Pamir mountains and on Kazbek and El'hus peaks have been (systematically carried out from 1926) gave an idea about the influence on the organism of high-altitude factors of different duration, about the physiological and biochemical mechanisms of adaptation to them and about the effectiveness and duration of acquired adaptation with respect to flights on aircraft under conditions of high altitudes. Into aeromedicine for the first time there was introduced an idea about the limit and the disruption of adaptation to hypoxia and there were developed the principles of high-altitude training for the purpose of increasing the stability of the organism to factors of flight [35, 49, 52, 64, 67, 92, 139, 187, 211, 236, 247, 258, 281, 320]. These data have also acquired theoretical and practical value of the contemporary stage of the development of space physiology.

In the 40's of the XX century in connection with the development of rocket technology and in anticipation of man's penetration not only into the upper layers of the atmosphere, but also for beyond its limits great attention was paid to the training and perfecting of aviation, medical and scientific staffs, many of whom, subsequently, became specialists in the field of space physiology.

The outstanding event in the establishment of space physiology as an independent discipline was the successful realization of the program of biological investigations carried out in the USSR on high-altitude geophysical rockets, by the 2nd artificial earth satellite, and also on the 2-5th spaceships-satellites [73, 77, 143, 176, 278]. These works obtained great recognition. The results of these works conducted on geophysical rockets were the first reported at the International Congress of Aeronautics, which took place in Paris on 3-8 December 1956 [193]. The significance of the mentioned experiments is difficult to overestimate. They made it possible to solve a number of medico-biological questions directly connected with the accomplishment of the subsequent stage of man's mastering of outer space.

The flight of the first in the world pilot-astronaut Yu. A. Gagarin on the spaceship "Vostok" on 12 April 1961 turned a new page in the history of the development of space physiology.

Subsequent flights on the ships "Vostok", "Voskhod", "Mercury" and "Demini" made it possible to accumulate extensive experimental material on the influence of the factors of space flight on the human organism.

Space physiology as the physiology of extreme states deals with the nonlinear dependences between the values of operational factors and the values of functional parameters of the living system. This hinders the deterministic approach to an appraisal of the data obtained in the flight and entacts the broad use of the computer and cybernetic conceptions. However, the theoretical foundations of space physiology are based on the classical ideas of materialistic biological science and can be briefly formulated in the form of the following three positions:

1. The organization of the internal environment of the organism in accordance with the conditions of its existence, in other words, the adaptation of physiological processes to the demands of the entire organism.

One of the adaptive factors ensuring the coordination of the vitally important functions of the organism under the modified conditions of its existence, is the constancy of the internal environment, characterized by the stability of the physiological, biochemical and other constants — body temperature, osmotic pressure, active reaction of the blood, metabolic processes, sugar concentration of the blood, ionic composition, arterial pressure and others. The relative constancy of the internal environment makes it possible for the organism to resist significant changes in the external environment.

2. The equilibration of the organism with the external environment.

The equilibration of the organism with the environment occurs dynamically and is accomplished due to the continuous release of energy, the source of which is metabolism. In the disruption of the functions of the organism, which is possible under conditions of extreme effects, disturbances can appear in metabolism, in the exchange of energy and in the removal from the organism of toxic products of metabolism, which are linked with changes of the optimum conditions of the vital activity of the cells and tissues. As a result the tissue and cellular elements become vulnerable and the functional progressively increasing shifts can lead to pathology in the entire organism. It follows from this, how important it is under conditions of extreme effects for the purpose of prophylaxis to prevent the disturbance and the exhaustion of all levels of nervous and humoral regulatory systems which delicately equilibrate the activity of the organism with the surrounding environment. The principle of the relative constancy of the internal environment of the organism is one of the basic in research ways and means of creating adequate artificial conditions of inhabitation and vital activity for man with respect to the carrying out of prolonged space flights, and also to the organization of orbital and interplanetary stations.

Under the influence of extreme effects consistent with the normal vital activity of organism, there arises an adaptive reorganization of the functions, regulating the complex interaction of the cerebral cortex, its subcortical structures (reticular formation, diencepholic region and the limbic system of the cortex), and also the neuroendocrine system (the hypothalomus-hypophysial suprarenal system). Adaptation somewhat extends the borders of the existence of the organism and leads to the displacement of the optimum zone and the attenuation of the dependence on external conditions. As a result there appears a new functional level of vital activity, which predetermines the new peculiarities of the reactions of the organism both to an immediate extreme influence (depending upon the strength,frequency, duration and intervals between the influences,etc.), and also to the period of restoration of the functions to the initial level (in the after-effect). The latter reflects the totality of the metabolic and structural changes in the individual systems of the organism and acquires the significance of an important integral index, helping to judge the functional state of the regulator systems, the reactive ability of the organism and its potential compensational possibilities.

The more intimately the functions of one or another organ are controlled by the highest sections of the central nervous system, the more rapidly and significantly their changes develop and the less time is spent on their restoration to the initial level. The same functions, which to a considerable extent also depend on the humoral mechanisms of regulation, especially those in the regulation of which there participate the links of intramural innervation, are distinguished under the same conditions by comparatively high stability. But as soon as their changes arrive, they are distinguished by the stability of their shifts, i.e., by the prolonged after-effect, characterizing the appearance of trophic disturbances in the individual organs even within the limits of a single functional system. Thus, for example, under certain conditions of the influence of hypoxia or transverse accelerations the bioelectric activity of the brain and heart was restored after several minutes, the activity of the gastric glands – after several hours, of the intestinal glands, judging from the changes of activity of the enzymes – only after several weeks. Consequently, the reactions of an after-effect of various duration for different organs give an idea about the correlation of a function of the organism and promote the manifestation of the hidden effects of the influence of tensions in the absence of sharp reactions and the establishment of the beginning of the "breakdown" of the organism as a single whole. The relative preservation under the indicated conditions of the dynamics of the cortical processes is accomplished, apparently, both by defense mechanisms, as well as by the subcortical centers of vegetative and neuroendocrine regulation, which attain here the highest limit of stress, frequently exceeding the norm.

3. The intimate interconnection of all systems of the organism, ensuring its integral response to different effects during differentiation of the shifts on the part of individual systems and organs.

The presence of a single system of control and communication in the living organism ensures both the greatest optimum, local changes, and also the overall reorganization of the whole organism in terms of adaptation to the given effect. The realization in flight of the most advantageous (for the whole organism) level of activity under conditions different from normal is accompanied by a whole series of transitional states. During flight there can be observed periods of expressed disorganization of functions, when the level of activity of the individual systems sharply increases. However, in the long run the process of adaptation is directed towards the subordination of the individual regulator sections by the cortical mechanisms. Here the higher levels of control preserve their normal functional ability due to the extreme stress of the lower levels of regulation.

The problems of the regulation of the physiological functions are intimately connected with the study of the normal variations of individual parameters and their rhythms. One of the most important indices of homeostatic equilibrium in the internal environment is the degree of synchronization of the individual parameters, in particular of the parameters characterizing the various levels of regulation, for example between the heart rhythm and the sugar content in the blood or the number of eosinophils. The external effects can have an influence both directly on the lower levels (for example, during overloads), as well through the central nervous system (the emotional factor, the change of the regime of work and rest). It is essentially important to estimate the range of the changes of not only the absolute and mean values of the parameters, but also their periodicity and synchronization, since without knowledge of these changes it is impossible to estimate the reaction of the organism and to prognosticate the probable deviations. This especially deals with prolonged observations with respect to crews of orbital and lunar stations and interplanetary ships. Here the prognostication should be carried out on the basis of a study of a number of fundamental and very sensitive indices of the functional state of the organism and of the levels of its regulation. It is necessary to attribute the degree of fluctuation and the frequency-phase response to the number of such indices. It is difficult to assume that the average and individual indices accepted in physiology at the present time can be sufficient for revealing the delicate changes lacated on the edge of the norm and pathology, against the background of the unusual, for the organism prolonged influence of weightlessness and other factors. Consequently, the problem of improving the existing and the search for new methodical procedures for studying the functional peculiarities of the healthy person (individuality, the role of constitution facts, biorhythm, etc.) continues to remain especially important in space physiology.

CHAPTER II

THE METHODOLOGIC PECULIARITIES AND THE METHODS OF SPACE PHYSIOLOGY

The specific character of the conditions, under which the organism is situated – the object of study of space physiology, does not allow the application of the existing extensive arsenal of classical methods and the recently developed instrumental electronic physiological methods of investigation. Therefore, one of the first problems of space physiology consists in the creation of adequate (to the conditions of space flight) and precise methodical procedures of registration and transmission of physiological information from on board the ship to earth.

1. Problems of the Transmission of Physiological Information from on Board the Spaceship to Earth

One of the essential peculiarities of space physiology consists in the fact that for the accumulation of the necessary scientific information it is necessary to use methods of telemetry. In astronautics physiologists, probably, for the first time had to collide with the necessity of strict coordination of the volume of transmitted information with the carrying capacity of the telemetering links. The presence of the large complex of objects involved in physiological measurement (the source of information, the on board equipment, the telemetric devices, etc.) caused the application in space physiology of the concept of the "measuring data system" [177, 73].

The complex of means for the telemetry of biological data received the name biotelemetric system.

The basic features of space biotelemetric systems are:

- the transmission of information at very close distances;
- the discrete character of transmission, depending on the parameters of the orbit and the geographic location of receiving stations;
- the limitation of the carrying capacity of the channels;
- the use of on board memory units for the accumulation of information;
- the simultaneous transmission of a large number of parameters;
- the necessity of collecting information under conditions of usual astronaut activity;
- the necessity of operational analysis of part of the transmitted information for the purpose of medical monitoring the astronaut.

Inasmuch as the weight and energy consumption of the telemetering equipment on board the spaceship are strictly limited, then both the power of the transmitter, and consequently the volume of the information transmitted to earth are also limited. In physiology the idea of information carries a clearly expressed semantic character. Questions of the sapience and the value of information are studied by special divisions of the information theory. Within the bounds of the general communication theory the problems of transmitting information are connected mainly with the number and the character of signals subject to transmission. For transmitting physiological information telemetric channels with a diverse transmitting capability within the limits of from 4,000 to 0.1 bits/s are necessary [19].

The problem of optimum loading of the telemetering channels acquires especially real significance in connection with the increase of the duration and distance of the space flights. The basic problem consists in ensuring the transmission of the maximum amount of physiological information while using the minimum carrying capacity of the channel [21].

The biotelemetric system interacting with the object of the investigation, the spaceship and the ground medical personnel is an example of a great class of systems having obtained the name information systems. We examine the collection system, the transformation and transmission of physiological information as a physiological information measuring system. Included in its composition are:

- the source of information (man or animal);
- pickups and electrodes;
- on board amplifying equipment;
- telemetering apparatus;
- systems of communication and television;
- apparatus for the recording and presentation of data on earth;
- a recipient of the information (physician-researcher).

The physiological information measuring system of the spaceship is very complex (cybernetic). Pickups and electrodes carry out the selection of the assigned information from the huge aggregate of signals produced by the living organism (the source of information). The onboard amplifying equipment ensures the transformation of the signals into a form suitable for subsequent transmission or memorization. The telemetric apparatus (onboard and terrestrial) next carry out the transmission and reception of the information. The ground medical personnel perceiving the received information, including the radio and television data, processes it into concrete decisions and exerts influence on the source of the information (the astronaut) through the center for flight control, through the command radio links, through the system of radio communication. The physiological measuring-information system of the spaceship is schematically shown in Fig. 1.

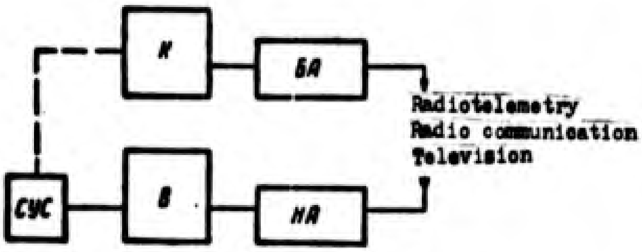

Fig. 1. The physiological measuring-information system. К = A = the astronaut; В = P = the physican; БА = OA = the on board apparatus; НА = GA = the ground apparatus; СУС = MCC = the means of control and communication.

Thus, in a physiological information measuring system there is feedback between the source and the receipient of the information. The time of the information cycle in the described system characterizes its quality from the point of view of performing the tasks of control and diagnostics. The more rapidly the processing of the information (coming from on board the ship) into control signals occurs the more effective is the physiological information measuring system.

Below there are given the attributes of certain important characteristics of the examined system.

The noise immunity of the system, i.e., its ability to carry out undistorted transmission of information in the presence of interferences, depends not only on the solution of engineering problems. Distortions can be connected with the incorrect arrangement of the transducers and electrodes, with the incorrect selection of the characteristics of the amplifying equipment or the inaccurate formulation of the requirements for the reproduction of the information. The reliability of the system has great significance. Reliability is defined as the probability of failure during a specific period of work. The least reliable elements of the physiological information measuring system are the transducers and electrodes, therefore their improvement is an important problem of space physiology. An integral index is proposed — diagnostic effectiveness, which can be defined as the ability to solve a specific number of problems in a given volume of transmitted information under given conditions of operation. Diagnostic effectiveness in the first place, depends on the selection of the recorded parameters and the algorithm of the processing of information, and also on the reliability, noise immunity and other indices of the quality of the physiological information measuring system.

The flying experiments with animals and the first manned flights in space made it possible to accumulate great experience in the construction of physiological measuring systems for ensuring the safety of flights and solving of research problems.

An important role in safeguarding high noise immunity, the reliability and the effectiveness of the physiological information measuring system of the spaceship is played by the electrodes and pickups. The development of transducers and electrodes for use under conditions of space flight presents certain difficulties [18, 72, 295]. The electrodes and transducers must have constant operating characteristics during prolonged and continuous operation, in the time of and after the effect of various factors of space flight. A serious problem is the fixing of the electrodes and transducers on the body of the astronaut or animal.

An important element of a system of physiological measurements on a spaceship is the on board radio electronic equipment. Its role consists in converting the signals from the electrodes and transducers into a form suitable for introduction into the telemetering equipment. In the process of converting the physiological signals their amplification, limitation by spectrum, integration or differentiation occur. The onboard equipment ensures the final coordination of the productivity of the source of information with the carrying capacity of the radio channel. The equipment mounted on board spaceships has a number of important distinctions as compared to ground instruments. These distinctions are connected, on the one hand, with the limitation by weight, the dimensions, energy consumption, and on the other hand — with the specific conditions of work of the equipment [5, 294, 366].

For the transmission of physiological information from on board the spaceship to earth telemetering systems with direct transmission (of periodic or continuous action) or systems with information memorization can be used. In orbital flights there are usually employed systems with direct transmission, which operate periodically (with transmissions) during the passage of the spaceship above the proper ground measuring points. Thus, for continuous direct transmission of data about the pulse rate of astronauts during flights on the "Vostok" ships was used a "Signal" transmitter. It worked during the whole time of the flight and emitted impluses in the rhythm of the heart contractions of the astronaut [276]. On "Voskhod" ships there was used an improved system of operational medical monitoring with simultaneous transmission of data about the pulse rate and respiratory rate. Moreover, the duration of the impulses emitted by the "Signal" transmitter in the rhythm of the heart changes depending upon the respiratory phase: for inhalation there were long signals, on expiration-short signals.

With the increase of the duration and distance of space flights the possibilities of transmission of information from on board to earth will be less due to the necessity of increasing the power of the radio transmitter and the limited reserves of electric power on the ship. Therefore, even now the development of new principles of organizing physiological changes in space is acquiring great importance. In Fig. 2 there are presented the stages in the improvement of the physiological measuring systems, starting with the flying experiments with animals to interplanetary flights.

In Fig. 2A there is shown the system of physiological measurements on the 2nd and 3rd Soviet spaceships-satellites. The objects of the investigation were two dogs (1 D and 2 D), to which

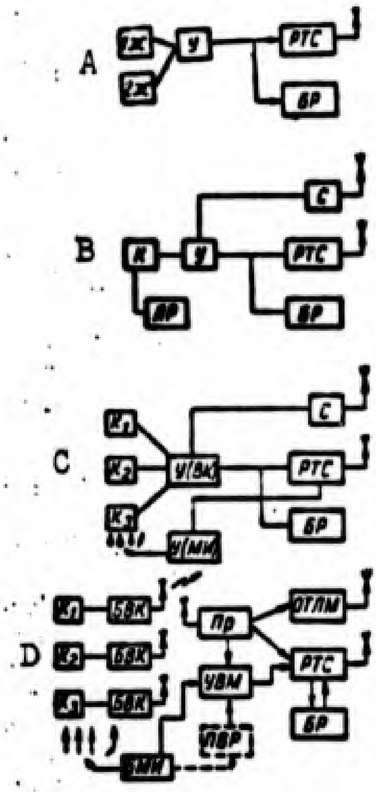

Fig. 2. Stages in the improvement of the physiological information measuring system. У = Am = amplifiers; PTC = TS = telemetering system; БР = OR = on board recorder; A = astronaut; AP = AR = autonomous recorder; C = S = "Signal" system; ВК = MM = medical monitoring; МИ = MI = medical investigations; БВК = MMB = MM block; БМИ = MIB = MI block; ПР = R = receiver; ПВР = PP = physician's panel; DC = digital computer; ОТЛМ = OTS = operational telemetric system.
Designation: К = D = dog.

fastened pickups and electrodes connected by leads to the amplifying apparatus. The physiological information was transmitted to earth via a standard telemetering system, and during the launch sequence when radio communication was impossible it was recorded on the on board memory equipment. In Fig. 2B there is shown the physiological information measuring system of the "Vostok" ships. Here there are two additional devices: the "Signal" transmitter for continuous transmission of the pulse rate (see below) and the autonomous recorder, which was attached to astronaut for recording pulse and respiratory rate during launch, parachuting and landing.

A new stage of physiological investigations in space was started with the flight of the "Voskhod" ship. The presence of a physician in the crew made it possible to significantly expand the volume of physiological investigations. Certain new methodological principles of collecting physiological information in space were tested. In particular, for the first time a functionally and constructively independent system of medical investigation was used. It should be borne in mind that the system of physiological measurements of the

"Voskhod" ships was chiefly intended for the purpose of medical monitoring. The obtaining of research information was a derivative of this main task. All transducers and electrodes during the whole time of the flight were on the body of the astronaut. With further development of this system the astronaut would be literally "decorated" with electrodes and transducers. Therefore, it was proposed to leave on the body of the astronaut only the minimum number of electrodes and transducers necessary for operational medical. The basic volume of research is performed with the help of transducers and electrodes, attached by the astronaut or physician himself only during the period of the making of the recording [23]. Thus, the system of physiological measurements is divided into a system of medical monitoring (MM) and a system of medical investigations (MI). On the "Voskhod" ship for the first time a system of medical investigations with detachable transducers and electrodes was tested. For medical monitoring during the whole flight electrocardiographic electrodes and seismocardiographic and pneumographic pickups were located on each of the astronauts.

In Fig. 2D there is presented a block diagram of the physiological information measuring system with respect to a multiseater spaceship intended for the realization of flights of great duration and distance. In order to ensure medical monitoring of the astronauts under conditions of free movement in the cabin of the ship, there is an intracabin telemetric system (minute telemetry). On the astronauts, besides the transducers and electrodes, there are placed minature amplifying-transmitting devices. The receiver is located on board and the information from its output can enter the operational telemetry system (OTS) — a variant of the "Signal" transmitter for continuous transmission of the most important data to earth. The data of medical monitoring with more complete volume can also be transmitted through the basic telemetering system. The most important element of a system of physiological measurements is the on board computer [4, 21, 277]. It will carry out the following tasks:

1. Compression of information for transmission to earth on

telemetric channels of limited capacity.

2. Performance of automatic medical monitoring with transmission to earth of generalized data about the state of the crew members. These data will also be projected on the on board physician's panel.

3. Automatic data processing and solving of diagnostic problems according to the medical monitoring and research programs. The development of diagnostic algorithms is acquiring great significance in correction with the possibility of using an onboard computer.

The coding of diagnostic procedures for the compilation of a machine program is connected with the accumulation of experience of the quantitative evaluation of both telemetric information obtained in space flights as well of materials from clincs and the physiological laboratory. Therefore, even now the use of clinico-physiological analogies in the analysis of data of space physiology is very valuable.

2. Methods of Physiological Investigations

Methods of Investigating the Cardiovascular System

Cardiological methods in space medicine have been developed to a greater degree than other methods. Electrocardiography has been used in all flying experiments without exception. For obtaining high-quality electrocardiogram recordings under flight conditions it is necessary to develop an essentially new method. Two bi-polar, pectoral leads were selected the MX (manubrium xyphoideus) and the DS (dextra-sinistra). The advantages of these leads consist in the facility of attaching the electrodes, the minimum level of muscular interference, the high diagnostic effectiveness. The DS lead has obtained the greatest application. Moreover, the electrodes with the help of a special breast belt were secured in the region of the fifth intercostal space to the left and to the right of the midsternal line. For limiting interference a frequency characteristic of the electrocardiographical amplifiers was selected in the 0.1-40 Hz range.

For registering the electrocardiogram for animals implanted electrodes were used. Special research was dedicated to the selection of the leads and to the establishment of electrocardiogram norms for dogs [30]. Great importance was attached to the monitoring of the pulse rate in space flights. A special instrument was developed — the electrocardiophone, which ensured the transmission of impulses in the rhythm of the cardiac contractions through the "Signal" transmitter, which operated continuously during the whole flight. For extensive analysis of the data of the pulse rate a method of variational pulsometry [28] was developed. Here there were calculated the distributions of the values of a dynamic series of RR intervals of the electrocardiogram with the plotting of variational curves or histograms. This method made it possible to estimate the state of the nervous regulation of the heart and to reveal predominance of the tonus of the sympathetic or vagus nerve. Recently a correlational and spectral analysis of the pulse began to be employed.

In space flights of animals the investigation of heart sounds was employed. A special method of "integral" phonocardiography [20] was developed, which provides the separation of the low-frequency envelope of audio-frequencies by the detection and integration of the output signals of the phonocardiographic amplifier (Fig. 3). Furthermore it is possible to use telemetering channels with considerably smaller capacities than for the transmission of a usual phonocardiogram.

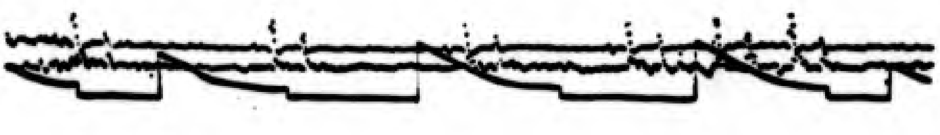

Fig. 3. Phonocardiogram of the dog Belka (average recording).

In connection with the necessity of studing the state of the contracting function of the myocardium under conditions of space flight there was developed a new method – seismocardiography [29]. This method is based on the transformation of the pulse movements of the thoracic wall into oscillations of an inert (seismic) mass, elastically connected with the object of measurement. Several variants of seismocardiographic pickups have been developed. The first of these was used for recording a seismocardiogram during the flight of the dog Pchelka on the 3rd Soviet spaceship sputnick. Subsequently, work was conducted in reference to the use of this method for investigating people. Seismocardiograms of healthy people [27] and seismocardiograms of sick people were studied. The adequate quality of the recordings and their high diagnostic value were shown.

The seismocardiogram (Fig. 4) consists of two oscillatory cycles (A1 and A2) corresponding to the forces appearing in the expulsion phase and in the reverse flow of the blood in the aorta and pulmonary artery at the beginning of the diastolic period. The amplitude of the oscillatory cycles to a definite degree reflects the strength of the cardiac contractions, and their duration makes it possible to judge the synchronism of the contractions of the right and left heart. The time of the mechanical systole can be determined according to the distance from the beginning of A1 to the beginning of A2. Seismocardiography was used during the flights of the "Vostok-5" and "Vostok-6" ships and the "Voskhod" ships. The pickup was located in the region of the breastbone and was attached to the clothing. The recording of the seismocardiograms was carried out on one channel with an electroculogram, which was possible in view of the distinction of the frequency spectra of the indicated processes.

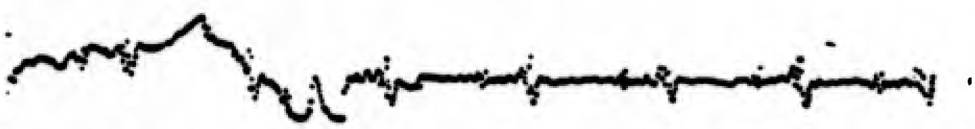

Fig. 4. Seismocardiogram of V. F. Bykovskiy (on the right there is recorded a superposition of an electroculogram).

With the help of seismocardiography there were obtained very valuable materials about the influence of weightlessness on the contractile function of the heart, however specific interest was also presented by the data of kinetocardiography used on the "Vostak-2" ship. For studing the state of peripheral blood circulation in animals methods of arterial oscillography and sphygmography were used. For recording sphygmograms in measuring the arterial pressure in the carotid artery a collar with a built-in tensolite transducer or piezoelement [31] was used.

Methods of Investigating External Breathing

At the present time in space research for studing the function of external breathing only the pneumography method is used. The most suitable for the conditions of flight experiment was the angle-data transducer, which is fixed in a breast belt in the region of the elastic inserts. This transducer makes it possible to investigate only the rhythm of breathing, since the amplitude of the excursions of the thoracic cavity does not reflect the volumes of pulmonary ventilation. Furthermore, the angle-data transducer requires careful individual adjusting, its calibration is difficult. Disturbances are observed on the recording during movements and conversation.

In American space investigations the method of impedance pneumography (measurement of the electrical resistance of the thoracic cage) was used. This method provides the obtaining of data about the value of pulmonary ventilation [311]. For use in future space flights spirographs and pneumotachographs are the most suitable. Anemometric transducers have been developed for the investigation of pulmonary ventilation. Methods providing an estimation of the gas composition of exhaled air deserve attention.

For investigating the function of external respiration indirect methods can also be used: electromyography of the respiratory muscles, the analysis of the respiratory variations of the elements of the electrocardiogram and the seismocardiogram [269].

Methods of Investigating the Neuromuscular System and the State of Efficiency

Investigations of human efficiency have paramount value for solving of practical problems of astronautics. The capacity for purposeful activity in controlling the ship and fulfilling other purposeful acts is intimately connected with the functional state of the nervous and muscular systems. The first investigations of these systems were carried out during flight experiments with animals using methods of actography and electromyocardiography.

For evaluating the activity of astronauts in flight the materials of radco transmissions, television data, and entries in flight logs were analyzed. The first space flights positively answered only the question about the actual possibility of carrying out specific work operations under the unusual conditions of space flight, but the question about the functional possibilities of the pilot-astronaut requires further investigations.

Motor activity was investigated with the help of special potentiometric and contact-rheostal transducers (for animals), by television observation, and also by certain artifacts of a number of physiological recordings. For example, a seismocardiographic transducer during movements of the object of investigation acts as an actograph. It is possible to make judgments about motor activity from the artifacts of the electroencephologram and an electrocardiogram.

Electromyograms were recorded for animals during the flight of the 3rd Soviet sputnik-spaceship. For lowering of the capacity of telemetering channels necessary for the transmission of relatively high-frequency (to 500 Hz) muscular biopotentials the signal on the output of the amplifier was rectified and integrated. An integral electromyogram reflects total muscular activity very well.

For evaluating the state of the central nervous system of a man under conditions of space flight the electroencephology method was used. Since medical monitoring of the astronaut was the main problem here, then only one lead of the electroencephologram was used. The spontaneous electrical activity of the brain was recorded. The electrodes were disposed on forehead-back of the head leads. The tapping by these leads is considered panoramic and has obtained application in anesthesiology [90]. In most cases rather qualitative electroencephalograms (Fig. 5) have been obtained.

Fig. 5. Electroencephalogram of V. V. Tereshkova (on the right the alpha rhythm is very evident).

For judging the state of the vegetative nervous system a method of recording the changes of the electrical conductivity of the skin was used. Two types of instruments were created: one for measuring the absolute values of skin resistance and its slow changes, another for recording of only rapid oscillations of resistance. An instrument of the first type was mounted on the "Vostok-3" and "Vostok-4" ship, an instrument of the second type — on the "Vostok-5 and "Vostok-6" ships. The electrodes in both cases were placed on the foot [2].

Under the conditions of space flight the manifold activity of the astronaut provides a large amount of material for judging his efficiency. But the carrying out of all elements of a flight assignment makes it possible to indicate only the absence of qualitative changes of efficiency. For determination of the quantitative shifts and especially of the coordination of the work processes an introduction to the flight program of specific, well apportioned actions is necessary. A method of programmed medical investigation requiring active participation of the astronauts has been developed. In the programmed investigation the time of the load, its quantity and quality is apportioned. An evaluation of efficiency can be carried out not only from the results of performing the assigned actions, but also from the shift of a number of vegetative and nervous-muscular indices at the time of the activity and during the aftereffect.

Methods of Investigating the Vestibular Apparatus

After his flight certain vestibular disorders were perceived in G. S. Titov; in the program of physiological changes methods for monitoring the function of the vestibular apparatus were included. A complex of special tests for evaluating spatial orientation and fine motor coordination was developed. There was introduced a method of recording the electroculogram — the biopotentials appearing during movements of the eyeball due to the difference of [ЭДС] (EMF) of its front and rear pole. For recording the electroculogram silver electrodes were used, which were built into resiling inserts connected with the helmet ("Vostok-3" and "Vostok-4"). Subsequently detachable minature electrodes were used, which were disposed in direct proximity to the peripheral angles of the eyes and are connected with amplifiers by push-button fasteners on the helmet. Although electroculography was used mainly for detecting nystagmus accompanying vestibular reactions, with the help of this method the oculomotor activity of the astronauts could be estimated, and there could also be analyzed the oculomotor reactions, performed in accordance with the given tests.

Further development of methods for objective appraisal of the state of the vestibular apparatus can proceed both in the direction of improving electroculography, as well as in the direction of studying the reactions to electrical stimulations, and also the movements of the head and trunk, written language and vegetative functions.

The method of programmed physiological investigation was used for the first time on the "Voskhod" ship. The participation of a physician in the flight provided the most optimum conditions for the first test (in principle) of a new research procedure, in which the active relationship of the astronaut to the measurement program has fundamental significance. On the "Voskhod" ship there was placed an instrument, making it possible to transmit on one telemetering link one of 4 parameters: an electroencephalogram, an electroculogram, a dynamogram or the motor acts of handwriting [3].

For dynamography there was used a manual electrodynamograph with a press force up to 20 kg. From the oscillogram it was possible to judge the force and rate of the compressions, i. e., the muscular efficiency. The motor acts of writing were recorded with the help of a transducer converting the movements of the pencil into electrical signals [24]. The transducer consisted of two sites rigidly secured by flat springs. On the upper site there was placed a sheet of paper. The movements of the pencil in writing caused a displacement of the upper site relative to the lower one. For registering the displacements there was an electromagnetic system in the transducer.

The program of research during the flight of the "Voskhod" ship consisted of sequential recording in the beginning of an electroencephalogram with open and closed eyes, then of writing (assigned figures and geometric figures) also with open and closed eyes and, finally, of the performance of a number of vestibular tests with the registration of electroculograms [ЭОГ] (EOG). The total time for performing the whole program was about 5 minutes.

C H A P T E R III

CERTAIN MECHANISMS OF PHYSIOLOGICAL REACTIONS DURING THE ACTION OF FACTORS OF SPACE FLIGHT

At present considerable experimental material has been accumulated about the influence of the factors of space flight on the living organism. Many reactions under conditions of flight occur differently than on earth. The overall effect of extreme factors, and also the influence of the unsual (for man) null-gravity state caused a number of phenomena representing, apparently, a qualitatively new level of functioning of the physiological systems of the organism [12, 73, 150, 177, 298, 361].

In order to understand the mechanism of physiological reactions, it is expedient to analyze the state of astronauts at all stages of flight, and also in the prelaunch and postflight periods. Such an analysis should be conducted on the basis of a certain general conception, for which we took the position of the higher stability of the corticalized functions as compared to the vegetative ones during various extreme influences. It is assumed that the central nervous system organizes the control of the vegetative levels of the organism in such a manner that the evolutionarily earlier functions, for example blood circulation and respiration (as stabler to extreme influences) change to a greater degree than the functions, which are phylogenetically later.

With the development of cybernetics the questions of the interaction of different physiological systems in the organism began to be examined from the period of view of the theory of information and the theory of automatic control [5, 20, 29].

As is known, the systems of a living organism simultaneously regulate a huge number of parameters. For the living organism both the homostatic maintenance of the constancy of the internal environment and the continuous dynamic equilibration with the external environment are characteristic. Equilibration in the organism as in a complexly organized system is based on the exchange of information between the individual nervous, neuroendocrine and humoral levels in the presence of multiple feedbacks.

It is important to note that to a specific degree autonomy is characteristic for the lowest levels of function regulation. If one were to examine as an example a two-component biocybernetic system, then its lower level (analogous to the vegetative level of a living organism) possesses to a specific degree characteristics of self-control, self-regulation and self-guidance. For realization of these properties the examined level should possess the necessary elements (Fig. 6): arrangements for perception of information [PI] (BX) and

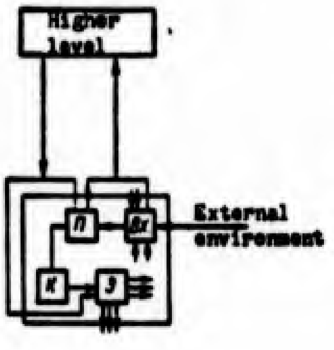

Fig. 6. Two-component biocybernetic system. BX – information input; П – information conversion; K – formation of guidance commands; Э – effector link.

its processing (П), arrangements for the formation of guidance commands (K) and the corresponding effectors (Э). For example, for the cardiovascular system these are the receptor zones in the wall of the ventricles and auricles, in the walls of the large vessels and in the lungs (as sensing arrangements), the extracardial ganglia and the centers of the medulla oblongata (arrangements for processing information and command formation), the sinus node and the actual musculature of the heart – effector.

The higher level of the regulation system provides control through its inherent programs, and by taking into account the data arriving on the feedback channels. Probably, some thresholds (regulated), exist limiting the volume of ascending afferentation. Signals arriving from the lower levels of regulation do not effect the program of work of the higher level and only after the appearance of super-threshold signals is control correction carried out. The higher levels of regulation inhibit the work of the lower levels, apparently, only when the organism as an integral system has to produce reactions protecting it from injury or destruction. Furthermore, the higher levels of regulation of the physiological functions compensate their functional possibilities through extreme stress on the lower levels of regulation.

In conformity with the evaluation of the reactions of the astronaut's organism to the effect of flight factors the examined conception indicates a way to differentiate the obtained facts by groups connected with the cortical and vegetative levels of regulation. Investigating only the two level of regulation, we, of course, artificially simplify the system of regulation to the physiological functions, since in reality there are considerably more levels. However, such a simplification in the first stages facilitates the understanding of the reaction mechanisms. At the same time such a division in general corresponds to a view of the organism as a system fulfilling two forms of regulation: equilibration with the external environment and maintenance of internal homostasis. Therefore with a certain approximation it is possible to assume that the two examined levels in general correspond to these two forms of regulation.

Prelaunch State of the Organism of the Astronaut

The prelaunch state of the organism has been well studied in athletic medicine. In the prelaunch state the activity of many systems of the organism is changed, especially of the central nervous system. Prelaunch reactions have a conditioned reflex character. Their intensity attains its maximum at the time of the launch [8, 31, 77, 97].

Space flight is a very great nervous and physical load. The astronaut obtains a clear idea of the difficulties anticipated in his flight during the training and tests. However, in the first minutes of the flight such factors, as acceleration, vibration, noise caused by the placing of the spaceship in orbit, act simultaneously and against the backgroud of the prelaunch functional changes of the systems of the organism.

In Table 1 there are presented data about the pulse rate of the first Soviet astronauts for the 4 hours [PL-1] (ПС-1) and for the 5 minutes (PL-2) before the launch. These data reflect the increase of prelaunch tension, although the behavior of the astronauts and their activity in this period were completely adequate, and also external calmness was preserved.

Table 1. Changes of the average pulse rate for astronauts in the prelaunch period.

Period	Yu. A. Gagarin	G. S. Titov	A. G. Nikolayev	P. R. Popovich	V. F. Bykovskiy	V. V. Tereshkova
ПС-1	64	68	72	56	66	84
ПС-2	108	104	112	118	120	128

Inasmuch as the somatic and vegetative components of the prelaunch reactions can be investigated, this makes it possible to obtain information about the state of the astronauts before the flight from the point of view of the interrelations between the cerebral cortex and subcortical centers of the brain. Excitation of specific subcortical formations of the brain is accompained by an increase of reactivity of the sympathetic nervous system carrying out mobilization of the whole organism and its preparation to the impending loads.

Depending upon the type of nervous system of the astronaut the manifestation of the vegetative components of prelaunch reaction can be different. Furthermore, the character of the impending flight has great importance. For example, in Yu. A. Gagarin, who was the first man to accomplish a space flight, there was noted a considerable increase of pulse rate before the launch. It was somewhat less expressed for G. S. Titov. For A. G. Nikolayev and P. R. Popovich, who carried out relatively equivalent flights, the differences in vegetative reactions before launch can be explained by typological peculiarities of the higher nervous activity [22, 25]. P. R. Popovich was more excitable; he belongs to the class of people with an "artistic" mentality (according to the terminology of I. P. Pavlov) with a choleric temperament. A. G. Nikolayev was more balanced and calm. He was a sanguine person or even a phlegmatic person. The study of the typological peculiarities of the central nervous system of astronauts is very important for the purpose of prognosticating their reactions not only at launch, but also during the flight. Attempts at such prognostication have already been undertaken [25] and it is necessary to assume that in the future they will lead to the creation of suitable computer for solving the prognostic problems of space medicine.

The peculiarity of the prelaunch states of astronauts can be to a large degree predicted as a result of an analysis of the data preflight trainings and test. This makes it possible to examine the prelaunch period both as a unique functional trial, as well as an additional, final test, to which the astronaut is subjected on earth. Prognostication of prelaunch reactions can be one of the most important parts of the overall problem of biological prognostication in space flight.

It is necessary to pay attention to the changes noted in the prelaunch period:

a) increase in the rate of respiratory movements;

b) decrease of the electrical resistance of the skin;

c) increase of the number of skin-galvanic reactions;

d) considerable decrease of "phasic sinus arrhythmin" [28];

e) shortened PQ, QRS, QT intervals of the electrocardiogram;

f) increase of the systolic and pulse arterial pressure [179].

All these changes indicate the excitation of the diencephalic centers of vegetative regulation of functions with shifts of relationships between the biologically active substances (acetylcholine, noradrenaline, histamine, serotonin), in particular with increased entry of adrenaline into the blood. Thus, in the prelaunch period in bringing about the reactions of the astronaut's organism along with the cerebral cortex the hypothomous-hypophysical-adrenal system actively participates. I. S. Balakhovskiy and I. G. Dlusskaya [33] showed that in different reactions of stress for pilots and parachutists the secretion of corticosteriods by the adrenal cortex sharply increases. According to I. V. Fedorov and I. M. Khazen [232], for pilots during complex flights on jet aircraft along with the increased excretion of 17-hydroxycorticosteriods with the urine the excretion of 5-hydroxyindolylocetic acid drops. The latter reflects the increased need of the organism for serotonin.

Propelled Flight Section

The first space flights of man and animals were preceded by numerous experiments on centrifuges with simulation of overloads of different value, which acted in different directions. Many investigations of the influence of overloads on the human organism were carried out by aeromedical physiologists. However, it is necessary to bear in mind that during the propelled section of the space flight qualitatively different influences are observed than during during flight in an aircraft and in experiments on the centrifuge. These distinctions are determined by the action of a number of additional factors, such as noise and vibration, and by the presence of a background of physiological changes preceding the launch. It is necessary to point out the complex of factors of the propelled section, keeping, of course, in view that the overloads are one of the main factors [179, 286, 386]. The necessity of taking into account the whole complex factors [overloads, vibrations, emotional stress] can be confirmed by the materials of investigations of the content of adrenaline and nonadrenaline in the urine of people subjected to the influence of overload [317, 399]. The amount of adrenaline increased even before the beginning of the experiment, and during accelerations it increased by 2-12 times; the amount of noradrealine increased during experiment only by 2-5 times. Therefore, the secretion of adrenaline depends more on emotions, and noradrenaline – on the action of overloads. It is known that the secretion of adrenaline and the variation of its content in the blood are connected with the reaction of the medullary layer of the adrenal cortex, whereas noradrenaline will be formed chiefly due to the excitatory processes in the sympathetic fibers of the nervous system and to it belongs the main role in regulating the reactions determining excitation of the sympathetic nervous system [99]. Thus, according to C. Mc. Goodal [316], cardiac sympathin contains from 7 to 26% adrenaline and from 74 to 93% noradrenaline.

Information about the state of the astronaut during propelled flight always contains overall data. This especially touches on such indices, as pulse rate, respiratory rate, body temperature, and arterial pressure. Materials of the investigation of the state of Soviet astronauts during propelled flight show that a mean pulse value of from 120 to 150 beats per minute can be considered optimum during the action of overloads in this section.

During propelled flight the astronaut is subjected to the action of overloads in a chest-spine direction (transverse overloads). However, in an emergency situation the appearance of accelerations along the head-pelvis axis is possible. One of the most important changes during the action of overloads is the disturbance of cerebral blood circulation, which leads directly to dynamic, unstable disturbances in the central nervous system. The application of the method of electroplethysmography made it possible to quantitatively estimate shifts in cerebral blood circulation of brain during change of gravitation [160, 161]. The maximum filling of the intracranial cavity with blood is observed during overloads of 1.5-2 units with a foot-head direction of the overload. During transverse overloads the changes of cerebral hyperemia are small even during great overloads of the order of 7-8 units.

The changes in the central nervous system during the action of overloads are caused not only by disturbances of the blood supply in the brain, but also by the influence of unusual afferent impulsation on the part of different organs and tissues. The study of the bioelectric activity of the brain during overloads made it possible to analyze its dependence on man's tolerance of the overloads. Furthermore, definite phases in the changes of the biopotentials was detected [38, 74, 122, 341], which, apparently, to a considerable degree are caused by the disturbance of the interconnections of the cortex and subcortex, induced by the decline of the blood supply of the brain [207].

Electrocardiographic investigation during the active section give direct information only about functions of automatism, excitability and conductivity of the myocardium. The pulse rate attains its maximum value immediately after the launch (during the 1st minute) and then slowly decreases. It is possible that the deceleration of the pulse rate depends on the degree of emotional stress. Thus, for A. G. Nikolayev the slope of the graph of the pulse rate during the propelled section was greater than for P. R. Popovich. The spike changes of an electrocardiogram during propelled flight depend basically on the position of the heart in the thoracic cavity. Accelerations along the chest-spine axis cause displacement of the apex of the heart towards the back which leads to the relative reduction of the R spike and the increase of the T spike.

The changes of the intervals of the electrocardiogram depend on the increase of the tonus of the sympathetic nervous system. They are shortened with respect to the duration of the R. R. interval.

It is extremely difficult to investigate hemodynamic changes under conditions of space flight during the action of overloads. Many authors [38, 219] attach great significance during the action of transverse overloads to the change of the conditions of blood circulation in the pulmonary artery system, which leads to disturbances of the function of external breathing. A. A. Kiselev

[105] showed that transverse overloads cause deposition of blood in the lungs, which leads to the deceleration of blood circulation and the decrease of the volumetic content of oxygen in the arterial blood; oxygenation decreases. However, the changes of the activity of the cardiovascular system during overloads are determined not only by mechanical causes, but also by neuroreflex reactions. These reactions depend on functional shifts in the central nervous system.

B. M. Savin [213] showed that during the action of overloads on the part of the central nervous system it is possible to observe reflex reactions of the compensator type and reactions promoting the development even sharper disturbances. An important role in the development of such reactions is played, apparently, by impulsation from baroreceptors of the vascular system, particularity of the vein receptors. The increase of venous pressure during the flight of animals on a rocket was recorded by V. V. Yakovlev [279]. The increase of arterial pressure was noted by many authors [11, 127, 338]. Reflex mechanisms lie at the basis of such functional manifestations observed in the experiment, as the increase pulmonary ventilation [17], and the increase of the muscular activity of abdominal press (prelum abdominale) [66].

Ye. B. Shul'zhenko [270] conducted investigations with animals subjected to the action of overloads in the chest-spine direction. One group of animals had intact carotid sinuses, the other – denervated carotid sinuses. The action of overloads of various values (from 3 to 9 units in sharp and chronic experiment) was investigated. In Fig. 7 there are given data obtained in a chronic experiment during the action of overloads at 9 units. In response to the action of overloads in both groups there is observed an increase of arterial pressure. However, for dogs with denervated carotid sinuses the reaction takes place with smaller displacements of pulse, minute volume, peripheral resistance and systolic pressure and with a certain delay. One of the important components of the overall discharging reaction of the circulatory system is the increase of minute volume, connected with the hyperfunction of the heart [180]; small changes of the minute volume for dogs with a denervated carotid sinus do not ensure the timely and necessary adaptation of the cardiovascular system to the action of overloads. The displacement of hemodynamic indices lasts longer for these animals than for the intact ones after termination of rotation. Thus, the reflexes from the baroreceptors of the carotid sinus, as well as from other receptor fields, play an important role in the compensator-adaptive reactions of the organism to the action of overload.

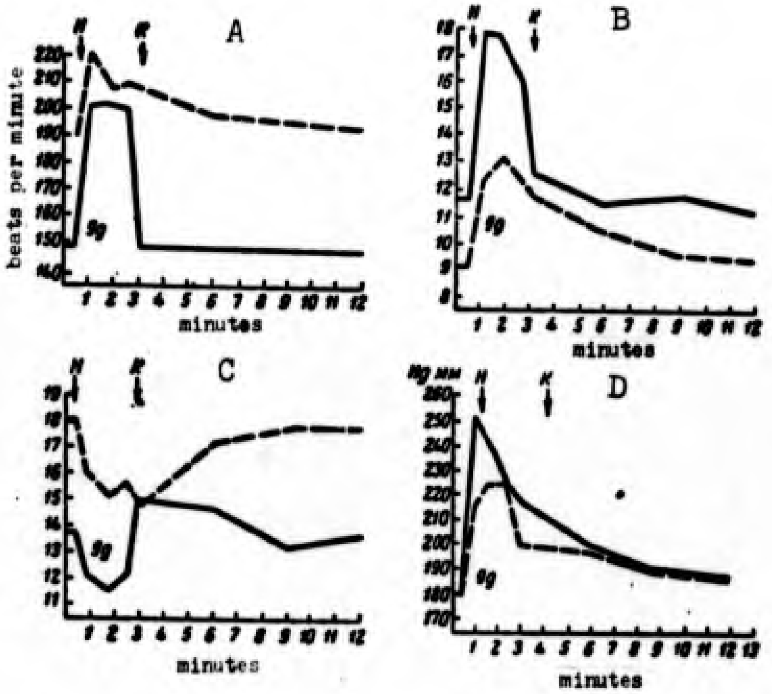

Fig. 7. Action of overload in 9 units on dogs with intact (solid line) and denervated (dotted line) carotid sinuses. A — pulse rate; B — minute volume; C — peripheral resistance; D — systolic pressure.

The reactions of the living organism to the effect of the factors of flight during the launch phase are determined by the hemodynamic and neurohumal mechanisms. The presence of overload aftereffect [14, 23, 118, 119, 154, 155, 162, 244] is very significant.

On the basis of the analysis of published data it is possible to distinguish two levels of mechanisms, ensuring the compensator-adaptive reaction of the organism to propelled flight: the cortical and vegetative level. The mechanisms of the cortical level - reflexes appearing as a result of:

1) the direct mechanical stimulation of the brain;

2) the stream of impulses from the receptor apparatuses;

3) the change of the blood supply in the brain;

4) the change of the level of activity of the endocrine system;

5) the change of the functional interrelations of the cortex and subcortex.

The mechanisms of this level possess a high capacity for compensation due to the strengthening of the activity of the mechanisms of the lower vegetative level.

The mechanisms of the vegetative level ensure compensation due to the reflex intensification of the activity of the cardiovascular system, respiration, metabolism and other functional systems. Furthermore, the existing reflex connections are mobilized and new ones are established. A number of reflex acts take place in an unusual manner.

As example it is possible to cite the course of the depressor reflex from the arteries of the lesser [pulmonary] circulation (V. V. Parin's reflex) during overloads. It is known that during stimulation of the baroreceptors of the pulmonary artery system the following phenomenon are observed: bradycardia, drop of the arterial pressure in systemic circulation and deposition of blood in spleen [175]. It has been positively established [105] that transverse accelerations cause an increase of pressure in pulmonary blood circulation. However, instead of a hypotensive reaction with bradycardia an increase of arterial pressure and tachycardia are observed. Only on the part of the spleen, apparently, is there preserved an "adequate" response to the stimulation of the receptors of pulmonary circulation. The blocking of the reaction from the pulmonary vessels to systemic circulation is easily explained by the simultaneous strengthening of the secretion into the blood of sympathins, causing a hypertensive and positive inotropic action. Thus, the cortical mechanisms when necessary suppress those components of vegetative reactions, which are unfavorable for the central nervous system under given concrete conditions. Therefore, in spite of the expressed deviations on the part of the systems of blood circulation, external breathing and other internal organs, the cerebral cortex suffers to a lesser degree. As it is known, during launching into orbit the astronauts maintained constant radio communications with earth, they reported their impressions and ran the radio equipment.

Thus, on the basis of the data obtained during space flights and laboratory experiments with the effect of transverse overloads it is possible to draw a conclusion about the presence of certain uniform regulator reactions, which are carried out by the organism for the purpose of protecting it from unfavorably operational factors. Such reactions are:

1. The activation of evolutionarily caused protective reflexes, including the primary activation of nervous and neurohumoral mechanisms for the purpose of preparing the organism for the impending effects of the factors of the environment.

2. The blocking of a number of reaction components, which are unfavorably reflected in the activity of the central nervous system.

3. The optimization of all reactions of the organism for the purpose of creating conditions for the best functioning of the central nervous system.

Orbital Section of Flight

The first data about the physiological reactions of the living organism to the conditions of orbital flight were obtained in 1957 during the flight experiment with the dog Layka. Simultaneously with the advent of weightlessness there appeared expressed motor activity and short-term quickening of the cardiac rhythm [32]. Layka's flight showed that the conditions of orbital flight do not cause any kind of pathological deviations.

At the present time there exists much information about the reaction of different functional systems of man and animals to the effect of the complex of factors of space flight. Weightlessness is only one of these factors, apparently, having paramount value, especially in prolonged flight.

The orbital section of flight can be divided into three parts, which are ambiguous with respect to the physiological state of the organism:

1. The first minutes and hours of the orbital flight, during which along with the factor of weightlessness there acts the novelty of sensations (emotional stress) and, mainly the aftereffect of overloads is observed.

2. The period of the effect of the factors of orbital flight, mainly which depend on its duration. It is possible to distinguish short-term (less than a day), diurnal, weekly, monthly and more prolonged flights.

3. The period immediately preceding the descent (4-6 hours before the beginning of the descent). At that time, besides the factors of orbital flight, there acts emotional stress - "the reaction to the return."

In the analysis of the materials of the propelled section it was shown that under extreme conditions the vegetative mechanisms assume the basic load, creating the most optimum conditions for normal activity of the cerebral cortex. In orbital flight, where the main effective factor is weightlessness, there is observed a very significant "easing" of the work of a number of organs and systems. First of all there is completely evident the fact of the decrease of the work of the heart in connection with the absence of the hydrostatic factor of blood circulation. The absence of the forces of terrestrial gravitation leads to a decrease of energy expenditure in the activity of the anti-gravitational muscles; the tonic stress of the skeletal musculature decreases. It is also important to note that in the null-gravity state the volume of afferent signals also decreases: signals proceeding from the periphery to the central nervous system. This, apparently, affects the state of the higher vegetative centers in the diencephalic region and the brain stem. It is possible to suppose that this leads to the decrease of the tonus of the sympathetic centers. On the whole the state of the organism under conditions of weightlessness can theoretically be characterized by the presence of an "unloading" reflex at all levels of regulation. Metabolism changes, and also the interaction of individual sections of the neuroendocrine system. However, there does not occur a corresponding lowering of the activity of the cerebral cortex.

Conversely, the conditions of space flight require from the astronaut complex and purposeful activity in controlling the ship. Exiting into open space, and in the future the fulfillment of various operations under its conditions present additional drastic demands on the central nervous system of the astronaut. Thus, in orbital flight for the organism there appears a new unusual situation, when the physical conditions of flight promote the "easing" of the basic vegetative functions, and the execution of the demands on the astronaut both as an operator and a member of the crew is connected with the intensification of these functions. In the end the indicated contradictory tendencies should lead to a certain stable equilibrium of the cortical and vegetative functions, ensuring the performance by the astronaut of the occupational obligations. As the flight of the American astronauts on the "Gemini-7" ship for 14 days testifies there is apparently, established some kind of more or less stable level of functioning, although it is impossible to say, whether it is final. Most likely, this is one of the intermediate stable states of the organism, after which new changes in the activity of different systems and organs can be observed.

The processes of transition from one state of the organism to another are of great interest, in particular, the processes of re-organization of functions in the first hours of the effect of weightlessness. The study of the mechanisms of such reorganization can put in the hands to the researchers the key to the prognostication of unfavorable deviations. Furthermore, a "struggle of contradictions" of the cortical and vegetative levels of the organism is very distinctly traced here and a number of phases develop, which constitute special states and which do not have analogies in physiology and pathology.

The indicated transitional processes can be well illustrated by an example of the analysis of data of the reactions of the circulatory system, which can be evaluated as integral responses of the vegetative level to some or other influences. To the investigation of the reactions of the cardiovascular system in space flight there has been dedicated a great number of works [26, 100, 103, 178, 319, 351]. Here there will be represented only certain materials necessary for the confirmation of the developed conception.

a) The rhythm of cardiac contractions. Frequency shifts of cardiac contractions can be connected both with hemodynamic factors (influx and eflux of blood), as well as with the regulational activity of the central nervous system (the changes of tonus of the brain stem and diencephalic vegetative nerve centers). Under conditions of weightlessness in the first period after the effect of accelerations during propelled flight marked emotional stress is still preserved, and metabolism is intensified. Both these factors are connected with the increase tonus of the sympathetic section of the nervous system, causing a high pulse rate. Normalization of pulse under conditions of weightlessness occurs considerably slower than on earth after special tests on the centrifuge, corresponding to the degree of load during the propelled section of space flight. Delayed normalization of pulse is observed both in animals, as well as in people and therefore cannot be explained only by the emotional factor. Apparently, the initial hemodynamic conditions [71] have a value, which are different for earth and weightlessness.

The average and absolute values of pulse rate in the null-gravity state on the 2nd and 3rd day of the flight are lower than in corresponding simulation experiments on earth. During sleep for all astronauts in flight the pulse rate was lower than during laboratory tests in a mock-up of a spaceship. Thus, for astronauts during flights at night the pulse was up to 40 beats per minute.

b) Excitability and conduction of the myocardium. Electrocardiographic investigations in flight made it possible to estimate the state of excitability and conduction of the myocardium. During the null-gravity state there were not detected any significant changes of the spikes and intervals of the electrocardiogram for the astronauts. There is a certain tendency towards lengthening of atrioventricular conduction. The Q-T interval is changed in conformity with the rhythm. The amplitude of spike T, as is known, to a definite degree is connected with the metabolic processes in the myocardium [234]. The lowering of the amplitude of T indirectly testifies to the decrease of the intensity of the metabolic process and to the myocardium. In orbital flights there were observed two types of changes of the amplitude of spike T: 1) progressive slow decrease (V. F. Bykovskiy, P. R. Popovich); 2) ascent with a subsequent faster lowering (V. V. Tereshkova, A. G. Nikolayev).

c) The contracting function of the heart. The most detailed data about the contracting function of the heart were obtained with the help of seismocardiography for the crew of the "Voskhod" ship and for V. F. Bykovskiy and V. V. Tereshkova. The duration of the mechanical systole (tA1A2) for all astronauts with the very first orbits of flight increased, as well as the mechanico-electrical index (K). For G. S. Titov on the kinetocardiogram there was also revealed a lengthening of the mechanical systole (Table 2).

The indices characterizing the structure of the seismocardiogram are: the amplitude and the duration of each of its cycles under conditions of weightlessness; they revealed distinct dynamics (see Table 2). The changes of the seismocardiogram during the first days of the flight are well traced for V. M. Komarov, K. P. Feoktistov and B. B. Yegorov. For V. V. Tereshkova and V. F. Bykovskiy due to the methodical peculiarities of the recording the qualitative data were obtained starting with the 2nd day of the flight.

Table 2. The dynamics of the indices of the kinetocardiogram (KKG) and the seismocardiogram (SKG) during orbital flight (mean values).

Indices of the KKG	G. S. Titov						
	before launch	orbit					
		2th	4th	6th	13th	15th	17th
t ms (s)..........	0,35	0,36	0,30	0,46	0,41	0,47	0,37
t em (s)..........	0,33	0,040	0,039	0,045	0,046	0,049	0,045

Indices of the KKG	V. F. Bykovskiy						V. V. Tereshkova			
	before launch	day of flight					before launch	day of flight		
		1th	2th	3th	4th	5th		1th	2th	3th
tA1 (s)..........	0,14	0,15	0,16	0,17	0,18	0,17	0,11	0,10	0,15	0,14
tA2 (s)..........	0,10	0,10	0,10	0,12	0,13	0,12	0,08	0,07	0,11	0,10
tA1A2 (s)........	0,32	0,38	0,35	0,37	0,37	0,30	0,26	0,33	0,40	0,37
A1/A2............	1,8	1,9	2,0	3,0	3,0	3,2	1,3	1,8	2,9	2,4

Indices of the KKG	V. M. Komarov								K. P. Feoktsitov			
	on earth	orbit			on earth	orbit			on earth	orbit		
		1th	7th	13th		1th	7th	13th		1th	7th	13th
tA1 (s)....	0,13	0,10	0,09	0,09	0,14	0,14	0,15	0,10	0,14	0,15	0,15	0,15
tA2 (s)....	0,14	0,06	0,10	0,06	0,11	0,11	0,10	0,09	0,10	0,11	0,10	0,10
A1/A2 (s)..	1,33	1,50	1,40	1,50	2,0	1,50	1,0	1,25	1,50	1,50	1,20	1,3
tA1A2......	0,30	0,27	0,34	0,35	0,27	0,32	0,38	0,35	0,30	0,27	0,35	0,35

Arbitrary designations: t ms (A1A2) – the mechanical systole; t em – electromechanical delay; tA1 – the duration of the 1st cycle of the SKG; tA2 – the duration of the 2nd cycle of the SKG; A1/A2 – the relationship of the amplitudes of the 1st and 2nd cycles of the SKG.

Designations: MC = ms; ЭM = em; СКГ = SKG; ККГ = KKG.

In the 1st orbit there was observed a considerable increase of the amplitude of the first cycle of the seismocardiogram. Then amplitude A1 gradually decreases, attaining towards the 7-13th orbit values, essentially less than during the pre-launch period. Such dynamics of A1 well agree with the ideas about the gradual lowering of metabolism and energy under conditions of weightlessness. Due to the sharp intensification of cardiac activity during the action of overloads in the first period of weightlessness there are still preserved the high minute volume and the increased speed of expulsion of blood by the ventricles. Moreover, the absence of gravitation considerably facilitates the work of the heart in moving the blood, which at first leads to relative increase of the speed of expulsion. Then gradually the cardiac contractions become commensurate with the new physical conditions (absence of gravitation) and amplitude A1 gradually decreases.

During the 1st day of the flight there is noted a tendency toward the increase of many exocardiac indices of blood circulation, characterizing the influx and efflux of blood: of the mechanical systole (A1A2), of the mechanical-systolic index [MSI] (МСП) and of the mechanical-electrical coefficient (K). The amplitude ratio A1/A2 almost did not change (see Table 2). From the 2nd day of the flight there is noted an increase of the ratio A1/A2 and the duration of the oscillatory cycles (tA1 and tA2) increases. These changes were stably preserved to the end of the flight. The duration of the cycles of the seismocardiogram depends on the amplitude-temporal relationships of the forces of the left and right ventricles. Even small disturbances of the existing relationships lead to a change of the duration cycles. Thus, it is possible to assume that the conditions of intracardiac hemodynamics under the conditions of weightlessness differ from the terrestrial ones. Apparently, there are distinctions in the operation of the right and left ventricles. If in the first period of weightlessness the heart adjusts to the new conditions of blood circulation due to the lengthening of the mechanical systole (for animals this period is not expressed), then the most stable adaptation is accomplished by the reorganization of the intracardiac coordination of the myocardium contractions. The tendency appearing at the end of the flight towards the normalization of the time of the mechanical systole makes it possible to draw a conclusion about the predominance in weightlessness of mechanisms of intracardiac compensation over the exocardiac ones. In order to estimate the clinico-physiological value of the indicated compensating mechanisms, R. M. Bayevskiy and Yu. N. Volkov [18] conducted a series of seismocardiographic investigations on patients with different forms of disturbance of the contracting function of the myocardium.

In Fig. 8 there are schematically presented the data obtained about the relationship of the "exocardiac" (with shading) and "intracardiac"

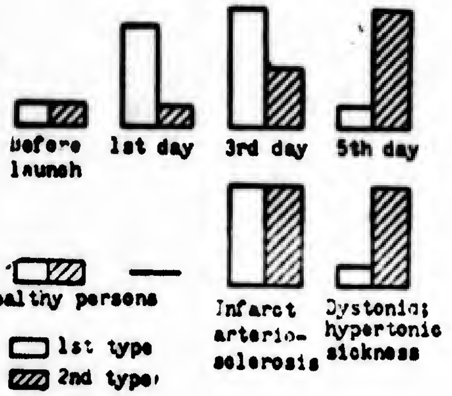

Fig. 8. The relationship of exo- and intracardiac factors of compensation for astronauts and for persons with various diseases.

(without shading) indices for conditions of space flight (the upper row) for healthy persons and for various groups of patients (the lower row). The diagram illustrates the dynamics of the reaction of the cardiovascular system in flight. On the 1st day of flight compensator reactions are accomplished due to the "exocardiac" factors. On the 2-3rd days of weightlessness (the end of V. V. Tereshkova's flight) there took place shifts on the part of the indices of both the "exocardiac," and also "intracardiac" group. Toward the end of the flight the main role in the process of the adaptation of the heart to weightlessness was played by the "intracardiac" factors.

Under normal terrestrial conditions the regulation of the reactions of the cardiovascular system is carried out by the centers of the vegetative nervous system, which reflexively change the influx and efflux of blood, and also the different parameters of the vascular system (the peripheral resistance and the volume of circulating blood). Thus, for healthy persons after a small physical load, during an orthostatic test and a Valsalva test there are observed characteristic changes of the mechanical systole, the mechanical-electrical coefficient and other indices, but usually essential changes of the "intracardiac" indices tA1 and tA2 are absent. The index A1/A2 is sometimes modified due to the increase of the hearbeat volume and the intensification of cardiac contractions caused by the increased influx of blood to the right ventricle. Consequently, the "exocardiac" factors mainly provide rapid initial compensation. With more serious loads (squatting, running, gymnastic exercises) the "intracardiac" factors are activated.

It is necessary to note that during neurocirculatory dystonia and during hypertonic sickness of the I-II stage in cases, when there are not yet expressed organic lesions of myocardium, and the functional shifts are small, compensation is also carried out mainly due to the "intracardiac factors." With the presence of organic disturbances of the heart or during its prolonged over-exertion accompanied by insufficient "intracardiac" compensation, there are additionally activated the "exocardiac" mechanisms, which are the last resource of the organism in its adaptation to the conditions of the disease [91].

For astronauts it was possible to distinguish three periods of compensation: 1) the period of primary action of the "exocardiac" mechanisms (the 1st day of the flight - the increase of the mechanical systole); 2) the period of simultaneous action of the "exo- and intracardiac" mechanisms of compensation (the 2nd to 3rd day of the flight - the increase along with the mechanical systole of the tA1, tA2); 3) the period of primary action of the "intracardiac" mechanisms after 3 days of flight - the primary increase of tA1, tA2.

All these three periods are well defined in the analysis of the data obtained in the flight V. F. Bykovskiy. The less prolonged flight of V. V. Tereshkova made it possible to detect only the first two periods. In this case we also see that in the beginning the reactions of the organism are caused by the "stress" state, and then there occurs the gradual adaptation to the unusual conditions of weightlessness.

d) The peripheral blood circulation. The possibility of disturbances in the peripheral blood circulation during the null-gravity state is caused by two phenomena: 1) the disappearance of the hydrostatic factor; 2) the decrease of vascular afferentation. In the opinion of L. E. Lamb [349], the appearance of a number of pathological vascular reactions it is possible due to changes in the stimulation of the carotid sinus. In the opinion of American authors [321], there is special danger for the organism in the lowering of the tonus of the venous system as a result of a disturbance of afferentation, which leads to orthostatic collapse due to the accumulation of blood in the veins. The orthostatic disturbances are explained by these authors by the lowering of the arterial pressure in astronauts in flight [346]. The first data about the change of arterial and venous pressure under conditions of weightlessness were obtained by J. R. Henry with co-authors during launchings of ballistic missiles. The study of the dynamics of arterial pressure during diurnal flight was carried out on the dog Strelka, as a result of which there was revealed a distinct lowering of pressure in the first 4-6 hours of weightlessness. Persistent lowering of arterial pressure in flight was observed in American astronauts [372] and the Soviet astronauts of the "Voskhod" ship [153].

e) Nervous regulation of cardiac activity. During the process of functional reorganization of cardiac activity there occurs the gradual adaptation of the circulatory system to the new physiological conditions. The important role in accomplishing the adaptive reactions, apparently, belongs to the vegetative section of the central nervous system. Under usual terrestrial conditions the establishment of a definite rhythm of cardiac contractions depends on the interrelationships of the vagus and sympathetic nerves. L. A. Orbeli considered that the increase of the tonus of the vagus nerve leads to instability of the cardiac rhythm [172]. I. S. Babchin and A. V. Lebedinskiy [15] observed an increase of pulse oscillations during direct stimulation of the cerebellum during an operation and consider this a result of the excitation of the parasympathetic system. It is also known that during sleep there occurs a strengthening of the parasympathetic and a weakening of the sympathetic influences on heart. The impression is created that during the action of weightlessness there occurs a strengthening of the parasympathetic and a weakening of the influences of sympathetic innervation on the cardiac activity. To such a vegetative reorganization there testifies the extension of atrioventricular conduction, relative bradycardia, increased pulse fluctuation, and also the decrease of arterial pressure.

During psychic and physical loads, for example, during the pre-launch period, there is observed, besides quickening of the pulse, a stabler rhythm of cardiac contractions, as if there were more rigid regulation of the automatic activity of the heart. A very important factor was the establishment of marked fluctuation of the pulse under conditions of weightlessness. This was first observed during flying experiments with animals [265]. Usually pulse arrhythmia in dogs reached 0.3 of a second, however, under conditions of weightlessness there were revealed values of arrhythmia 2-3 times greater than on earth. Increased pulse fluctuation was observed in the first flights of Yu. A. Gagarin and G. S. Titov. The statistical evaluation of pulse fluctuation made it possible to judge the state of cardiac automation during orbital flight [179].

The analysis of a dynamic series of values of RR intervals of the electrocardiogram on a 2-3 minute recording gave extremely interesting materials (Table 3). First of all it showed that the values of the statistical indices in flight are closer to the data obtained on earth at night time than in the morning hours. In the pre-launch period all statistical indices are distinguished by their low values. The standard deviations and coefficients of variations under conditions of weightlessness are larger than the morning and less than the night terrestrial values (with the exception of the coefficient of variations at night for V. F. Bykovskiy). We see that at night not only the mean value of the RR intervals is larger than during the day, but also the standard deviation, and Δx is considerably higher than the daytime values. This makes it possible to assume that under conditions of weightlessness the functioning of the "rhythm driver" indicates the predominance of parasympathetic influences over sympathetic ones.

Table 3. Results of a statistical analysis of a dynamic number of RR intervals of the electrocardiogram of astronauts V. F. Bykovskiy and V. V. Tereshkova.

Statistical indices	On earth		5 minutes before launch	In orbital flight				
	in the morning	at night		3th	23th	39th	51th	71th
M (s)	0,92	1,38	0,49	0,82	0,89	0,98	0,98	1,04
σ (s)	0,083	0,123	0,033	0,096	0,124	0,099	0,097	0,114
V (%)	9,0	8,9	6,7	11,7	13,9	10,1	9,8	10,9
ΔX (s)	0,30	0,50	0,20	0,50	0,55	0,60	0,55	0,45

V. V. Tereshkova

Statistical indices	On earth		5 minutes before launch	In orbital flight			
	in the morning	at night		2th	19th	38th	48th
M (s)	0,64	0,95	0,47	0,72	0,94	0,87	0,76
σ (s)	0,051	0,196	0,030	0,098	0,145	0,100	0,107
V (%)	7,9	20,6	6,3	13,6	15,3	11,4	14,6
Δx (s)	0,25	0,50	0,20	0,50	0,65	0,45	0,55

Arbitrary designations: M — arithmetic mean; σ — standard deviation; V — coefficient of variations; ΔX — difference between the maximum and minimum values.

Besides it is impossible to forget about the collaborative participation of the sympathetic and parasympathetic sections of the nervous system in the best adaptation of the organism to the conditions of weightlessness, which finds its expression in the adequate change of the relationships of the content in the blood and tissues of the organism of vagotropic and sympaticotropic substances.

The question of the role of the sympathetic reactions to the background of the increase of parasympathetic tonus has practical value in examining the data of blood circulation under conditions of weightlessness in connection with the state of the central nervous system. An analysis of an electrocardiogram recorded during sleep under conditions of weightlessness for V. V. Tereshkova did not show an increase of pulse oscillations (as on earth), but conversely, its decrease, although a bradyrhythmic reaction (Table 4) normal for sleep was observed. Thus, there is simultaneously noted a pulse reduction indicating an increase of tonus of the vagus nerve and a decrease pulse fluctuation, which is observed during an increase of

Table 4. The change of the rhythm of cardiac contractions in sleep for V. V. Tereshkova.

Conditions	$M_{бодр}/M_{сна}$	$\sigma_{бодр}/\sigma_{сна}$	$\Delta X_{бодр}/\Delta X_{сна}$
On earth............	0.67	0.26	0.44
In weightlessness...	0.76	1.78	1.50

the tonus of the sympathetic nerve. One of the possible explanations of this phenomenon can consist in the acknowledgement of the important role of the relative increase of afferent impulsation in sleep, which leads to stimulation of the sympathetic centers. There does not simultaneously occur a lowering of the high tonus of the parasympathetic section of the nervous system.

The materials about the influence of weightlessness of the cardiovascular system, obtained during the execution of space flights by man and animals, are still insufficient to completely reveal the mechanisms of the reorganization of the physiological functions of the organism under conditions of orbital flight. However, there is already beginning to appear a certain tendency towards an understanding of the process of reorganization as consisting of a number of phases and individually caused. Moreover, in spite of a number of noticeable shifts on the port of the vegetative functions, the higher cortical functions preserve their stability at least within the limits of those demands which were made on the astronauts during the flight of the "Vostok" and "Voskhod" ships.

f) <u>Cortical mechanisms of regulation</u>. At the present time there is still too little data to form a complete judgement about the state of the cortical mechanism under conditions of weightlessness. It is important to note that in past flights not one of the astronauts had any kind of neuropsychological disturbances, and, conversely, there was noted good efficiency.

Complex problems were also faultlessly carried out by A. A. Leonov in open Cosmos. Efficiency under conditions of weightlessness, in the opinion of all the astronauts, was not decreased. An analysis of radio conversations shows the accuracy and adequacy of the reports from space. Work with toggle switches, a telegraph key and a movie camera not cause difficulties. Concerning the absence of essential changes of motor coordination under conditions of orbital flight it is possible to judge on the basis of the fact that the astronauts in flight carried out manual orientation of the ship, made entries in the flight log, performed psychological and vestibular tests, took food and conducted special biological experiments.

In the opinion of B. B. Yegorov, the possibility of finely coordinated movements in flight is not upset. This means that the compensative-adaptive mechanisms of the whole organism provide normal functioning of the higher sections of the cerebral cortex [148]. It is necessary to consider that the increased reliability of the brain in this case is also caused by the considerable stress of the subcortical compensative mechanisms.

In an analysis of the handwriting of astronauts A. G. Nikolayev and P. R. Popovich from entries in the flight log there were detected certain changes during the first hour of the stay in the null-gravity state [151]. An analysis of the coordination of motor acts for astronaut B. B. Yegorov during flight was conducted with the help of a special device - a writing instrument providing the transmission of data by telemetry to earth. The obtained materials indicate that under conditions of weightlessness there is observed a certain slowing down of writing and a decrease of the accuracy of finely coordinated movements. According to L. A. Kitayev-Smyk [109], under conditions of short-term weightlessness there occurs a decrease in the accuracy of kinethetic change and time perception, and also a disturbance in the speed and exactitude of motor reaction [96].

All these phenomena, undoubtedly, are connected with the change of muscular tonus, which was experimentally demonstrated by many researchers [102, 120]. A definite role in the appearance of these phenomena can also be played by shifts in the central nervous system, in particular by reactions of the vestibular apparatus [41, 61, 62].

All the noted (on the cortical level) shifts are not so considerable, in as to cause noticeable deviations in the occupational activity of the astronaut or to hamper the performance of his assignments. However, in more complex future flights, when the activity of the astronaut will become more varied and differentiated, various minor deviations in muscular coordination or individual neuropsychic changes can acquire serious significance. Therefore, one of the important practical problems of space physiology is the development of methods for profound evaluation of the state of the cortical mechanisms of regulation.

g) Reactions of the entire organism. Complex aberrations of the cortical and vegetative levels of regulation create an unusual number of different states during the period of the whole flight and especially during the first several days of the effect of weightlessness. The adaptation of the organism to the new conditions of existence — a prolonged and complex process, which is not completed in 5 or even in 14 days. Nonetheless we are sure that the dynamics of the adaptive reactions at the beginning of period of adaptation to a considerable degree determines the further course of the adaptational process. At the present time there are bases for distinguishing three phases in the adaptive reactions of the physiological systems of the organism under conditions of weightlessness.

1. A transitional phase, in which there are observed changes caused mainly by the aftereffect of overloads and emotional stress.

2. A phase of incomplete adaptation, which lasts, apparently, 8-12-16 hours. In this phase there occurs a reorganization of the regulator mechanisms; there can be observed various vestibulo-vegetative shifts and reaction of the "stress" type.

3. A phase of relative stable adaptation, during which there begins to appear a certain stabilization of the functional state of

the organism. Moreover, its individual peculiarities have great significance.

More prolonged space flights will make it possible to observe living organisms in a state of complete adaptation to the new conditions. However, one should note a number of factors hampering complete adaptation. Thus, under conditions of weightlessness phenomena takes place, which are similar to prolonged hypodynamia: the return of venous blood to the heart is disturbed; the vascular tonus decreases; the volume of circulating blood decreases. Simultaneously there is observed a lowering of the tonus of the sympathetic section of the nervous system and a decrease of the secretion of noradrenaline [318]. The tonus of the parasympathetic system increases. In connection with this many authors attribute paramoung value to the phenomena of orthostatic deficiency under conditions of prolonged space flight [128, 152, 315, 349, 385].

The Reaction of the Organism to the Descent Section

The descent section is the most complicated with respect to the character of influences on the organism of the astronaut. Even before the beginning of the descent there is observed strong emotional stress. Inasmuch as it appears against a background to prolonged weightlessness many reflex reactions occurs somewhat unusually. In this period there is always observed a quickening of pulse and respiration; instability of the electrical resistance of the skin appears. Similar reactions to return appear 2-4 hours before the beginning of the descent.

In Fig. 9, on which there is given a schematic recording of a seismocardiogram of astronaut V. V. Tereshkova at a time of strong emotional stress before the beginning of descent, there is seen distinctly a third oscillatory cycle on the seismocardiogram. The presence of this additional cycle indicates the appearance of additional forces (accelerations) at the beginning of the diastolic period. It is most probable that these forces are connected with the more rapid filling of the heart. A similar picture can be

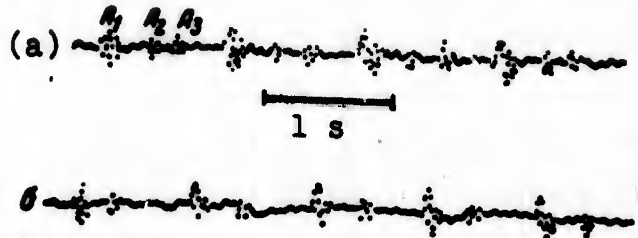

Fig. 9. Seismocardiogram on the 3rd day of the stay in weightlessness (b). The appearance of a third oscillatory cycle on the seismocardiogram for V. V. Tereshkova before descent (a).

observed during the increased influx of blood to the ventricles, i.e., during deposition in the pulmonary vascular channel and the venous system [334]. Emotion stress causes a sympathicotonic vascular reaction of the hypertensive type. During sharply arising reflex hypertension in systemic circulation blood is displaced into pulmonary circulation; the volume of blood in the lungs and pressure in the pulmonary vessels [180] is sharply increased. With this there are created the conditions for accelerated filling of the left ventricle and, subsequently, for the appearance of a third, additiona, cycle of the seismocardiogram. The similar situation, however, is short-term and transient. Thus, in flight the presence of a third cycle on the seismocardiogram was observed for only about 15 seconds. It is apparent that the increase of pressure in the pulmonary vessels leads to the appearance of an unloading reflex reaction, which consists in a pressure drop in the arteries of systemic circulation, the appearance of bradycardia and the deposition of blood in the spleen [175]. The course of the indicated reflex reactions under conditions of weightlessness is facilitated by the fact that when compared with terrestrial conditions afferentation from the baroreceptors is impoverished and against this background relatively weak signals from the vascular receptor zones can appear as actuating signals for depressor reactions of pulmonary of blood circulation. Furthermore, in the absence of gravity more favorable conditions are created for the deposition of blood in the lungs than in the venous system of the pelvis and the lower extremities.

During the operation of the retrorocket assembly of the spaceship the astronaut experiences the action of a small overload, which in its absolute value is even less than normal gravity on the surface of the earth. However, this overload acts after a prolonged stay under conditions of weightlessness and causes considerable quickening of the pulse. After deactivation of the retrorocket assembly weightlessness again appears. The pulse rate is somewhat reduced. Then in proportion to the entry into the dense layers of the atmosphere there is observed a gradual increase of the values of accelerations acting in a chest-spine direction. According to the subjective impression of the astronauts the transition to increased gravitation occurs smoothly, but the overloads are more severe than those during propelled flight. Almost all astronauts experienced a feeling of compression in the chest and stomach region [57, 183, 184].

In the majority of flights the Soviet astronauts landed by catapulting (ejecting) from the spaceship with the subsequent descent by parachute. Ejection is a very important part of the descent. The shock overloads arising during ejection were borne well by the astronauts, but for this there is required an exactitude of actions, composure and the adoption of a specific pose, which cannot be accomplished without emotional and physical stress. After ejection the registration of the rate of the pulse and respiration is carried out only on an autonomous recorder – a small magnetic recorder located in the [PEK] (HA3) (portable emergency kit) of the astronauts. The continuous registration of these important physiological indices during the whole period of descent is ensured.

The complexity and dynamism of the period of descent caused by the alternation of different forms of influences on the astronaut, cannot be completely simulated on earth. Tests on the centrifuge, ejection, parachute jumps are included in the program of astronaut training however in actual flight all these loads act on the organism, located before that force prolonged time under conditions of weightlessness. Even before the first flights of man and animals there existed apprehensions with respect to the tolerance by the living organism of the descent phase. Experience has shown that orbital manned flight with a duration up to 5-14 days does not cause any shifts, which would essentially lower the tolerance of descent. Not one astronaut, either Soviet or American, during the descent phase has observed significant deviations in the state of his health.

The Postflight State of the Organism of the Astronaut

The investigation of the morphological and biochemical composition of the blood of animals accomplishing flight on rockets showed that that there are changes on the port of the leucocytes and disturbances of coagulability: neutrophilic leucocytosis with a shift of the formula to the left, a certain increase of the content of calcium and the level of prothrombin and consequently a decrease of the time of blood coagulation [101]. These changes in the blood, apparently, are connected with disturbances of the state of the hypophysical-suprarenal system, which appear as a result of a reaction of "stress" type. According to A. A. Gyurdzhian with co-authors [84], in all animals accomplishing a diurnal space flight (Belka and Strelka), there were observed changes of the biochemical indices of the blood and urine, indicating a certain inhibition of protein metabolism. These changes vanished on the 13th to 23rd day after the return to earth.

Postflight examination of the astronauts was begun at the landing site and was then continued at the station hospital. The basic physiological changes are observed in the first days after the flight. Immediately after landing the astronauts are somewhat excited and fatigued. Vascular lability and orthostatic instability are noted. The American authors pay especially great attention to the orthostatic phenomena. Goodal with co-authors [318] showed that one of the causes of the decrease of vascular tonus is the drop of the activity of sympathens in the blood and the decrease of the secretion of noradrenaline. The experimental data of Soviet authors about the increase of the tonus of the parasympathetic system under conditions of prolonged weightlessness [28] corresponds to the hypotheses of the decrease of activity of the vasomotor centers. After flight there was detected a decrease of the elastic modulus of the vascular wall. Changes are absent in the electrocardiogram, the ballistocardiogram and phonocardiogram.

A certain increase of pulmonary ventilation was noted. For A. G. Nikolayev oxygen intake and carbon dioxide expiration increased respectively by 24 and 30% [70].

The biopotentials of the brain for the majority of astronauts were somewhat modified: a certain exaltation of the alpha rhythm was observed during the first days of flight. For V. V. Tereshkova there was noted a decrease of the amplitude of the brain biopotentials [70].

As is evident from Table 5 the greatest weight loss among Soviet astronauts was for V. F. Bykovskiy, the least – for Yu. A. Gagarin. Apparently, there is a certain dependence of loss of body weight on the duration of flight. One may assume that weight loss occurs not only in connection with the stresses during the propelled flight phase and the descent phase, but also in connection with the effect of weightlessness, causing disturbances in water-mineral exchange and in metabolism.

Table 5. Changes of body weight of astronauts after space flight.

Astronaut	Weight before flight (in kg's)	Weight loss (in kg's)
Yu. A. Gagarin...	69.5	0.5
G. S. Titov......	62.6	1.8
A. G. Nikolayev..	68.0	1.6
P. R. Popovich...	74.8	2.1
V. F. Bykovskiy..	66.6	2.4
V. V. Tereshkova.	58.0	1.9

Flight also had an effect on the state of the peripheral blood (Table 6).

Table 6. Changes in the composition of peripheral blood of astronauts after flight.

Index	A. G. Nikolayev		V. F. Bykovskiy		V. V. Tereshkova	
	before flight	after	before flight	after	before flight	after
Hemoglobin, g/100 mℓ......	15,4	15,2	14,4	14,6	13,0	12,5
Erythrocytes, thous/mm^3...	5 250	4 720	5 080	5 080	4 020	4 100
Thrombocytes, thous/mm^3...	357	349	370	294	249	238
Leucocytes, thous/mm^3.....	8,0	18,3	6,3	8,5	7,3	11,6
Neutrophils, %...........	64	67,5	55	63	66	71,5
Lymphocytes, %...........	26	25,5	37	26	26	18
Eosinophils, %...........	4,0	9,5	1,0	0,5	1,0	0,5
POЭ, mm per hour.........	5	15	2	4	5	13

POЭ = Sedementation Rate (erythrocytes).

Biochemical investigations of the blood and urine have shown an increase of the content of serumal mucoids, a considerable decrease of Dische-positive substances in the diurnal portion of the urine, an increase of the activity of desoxyribonuclease, a considerable increase in the secretion of hydroxycorticosteroids with the urine. Diuresis increases on the first day after flight [70]. The content of serotonin the blood [182] decreases. Albumen (protein) is detected in the urine, the excretion of creatine increases.

Important to note that all disturbances on the port of the organs of blood circulation, respiration and central nervous system vanished in 2-3 days, and changes on the port of the formed elements of the blood and of the biochemical indices of the blood and urine were normalized in 2-3 weeks [70]. According to the increase of the duration of orbital flights there is not excluded the disadaptation of the system of blood circulation and the other systems of the organism with respect to conditions of prolonged orbital flight can be very significant. Rapid transition from conditions of prolonged weightlessness to normal terrestrial gravitation in this case can lead to unfavorable consequences. One of the most important problems of space physiology – to find methods of early diagnostics of such degrees of disadaptation, which are already dangerous. This is essentially a problem of the prognostication of the tolerance by the astronaut of the descent phase and of the subsequent stay under conditions of normal gravitation after an orbital flight. Such prognostication can give the bases for the selection and design of regimes of artificial gravitation. Apparently, there exists a sufficiently clear correlation between the data of pre- and postflight investigation, between the reactions to propelled flight, to orbit and during descent. However, a transition from approximate qualitative appraisals to exact quantitative ones is necessary, which is possible only through broad cooperation between space physiology, biophysics, cybernetics and mathematics.

CHAPTER IV

THE DIGESTIVE SYSTEM AS AN INDICATOR OF THE REACTIONS OF THE ORGANISM TO EXTREME EFFECTS

The contemporary theoretical ideas about the actuating and adjusting regulator mechanisms of the glands of the gastrointestinal tract, formed by the labors of the Pavlov Physiological School [10, 13, 53, 132, 175, 204, 222, 235, 263], make it possible under conditions of extreme effects to produce an appropriate differential analysis and to investigate the established relationships between the higher sections of the central nervous system and the internal organs. The gastrointestinal tract is a fine reagent of a number of nervous influences [95]. Great possibilities exist for the study of processes occurring on the tissue and molecular levels (mitotic cells division, enzyme formation, reparative regeneration, etc.). For example, it is known that various sections of the stomach and intestine possess different mitotic activity. Starting with the pylorus, it is the most intense in the small intestine and the ileum [136]. It is also known that the diurnal variations of mitoses in the mucous membrane of the fundus ventriculi are more weakly expressed than in the pyloric part. Mitoses are observed both in the chief, and also in the parietal cells, where their regeneration occurs with considerably less speed than the surface epithelial and mucous cells of the neck. The speed of auto-regeneration in the whole fundus gland is equal to 10.2 days, and the surface epithelial and mucous cells of the neck – 4.95 days [228]. These "slow" constituent processes of biological regulation can be used as an indication of the remote consequences of various extreme influences on the living organism.

The study of various extreme effects (hypoxia, accelerations, physical loads, sharp changes of ambient temperature, radiations and so forth) on the activity of the organs of the gastrointestinal tract of man and animals revealed the presence of specific disturbances, and the established regularities have theoretical and practical value for aviation, athletic and occupational medicine [49, 87, 224, 233].

Experiments on rats, where the influence of isolation, limitation of mobility, noise and other factors on the formation of gastric ulcers, are of interest. It was found that laboratory rats are extremely susceptible to the formation of gastric ulcers during the limitation of mobility [293, 348].

Investigations were also conducted on monkeys [292], in particular for the clarification of the physiological mechanisms of the formation of stomach ulcers during extreme effects [9, 156, 168].

An analysis of the neurophysiological mechanisms of the formation of stomach ulcers with respect to these conditions showed the role of the hypothalamus, the anterior section of which influences through the vagus and splanchnic nerves, and the posterior – renders hormonal influence through the hypophyseal-suprarenal system. The mechanism of gastric ulcers, the cause of which are emotional effect, is connected with the activity of the limbic region of the cerebral cortex [309]. Efferent nervous connections of the stomach, leading from the hypothalamus and other centers of the brain stem, are the object of intensive study [76, 131, 190]. Therefore, the use of the neuroglandular apparatus of the digestive system as an indicator for ascertaining the reactions of neuroregulation under conditions of space flight is valid [204, 233, 242].

The Influence of Accelerations on the Functions of the Digestive System

It has turned out that space physiology has given the digestive system altogether insufficient attention. Moreover, it was assumed that its functions in space flight are not disturbed. It is natural, that the study of the activity of the organs of the gastrointestinal tract under conditions of the effect of factors of space flight not only from the above-mentioned general-physiological positions, but also from positions of the physiology of digestion is acquiring very important application value.

By the study of the effect of accelerations on the organs of the gastrointestinal tract and primarily on the neuroglandular apparatus we have attempted, within the limits of the possible, at least on the basis of the data of an analysis of one of many simultaneously acting extraordinary (by force) stimuli, to create a concept about those functional and structural manifestations in the organism, which can appear during the launch of a spaceship and thereby to predetermine the influence of weightlessness.

In organizing the investigation seemed most promising to proceed from the position of the Pavlov school concerning the fact, that the value of the nervous and humoral mechanisms of regulation is unequal with respect to various organs of the digestive system [173, 204, 205]. In connection with these a study was conducted of the dynamics of the secretion of the salivary, gastric and intestinal glands, and also of the periodic contractions of the stomach of dogs during the effects of radial accelerations of various value and direction.

As a rule, during the effect of acceleration in a craniocaudal direction with a value of 3g and a duration of 60 seconds inhibition of unconditioned-reflex salivation was noted. The effect of accelerations in the same direction, but with a larger magnitude (5-9g, with a duration of 20-60 seconds) left an expressed aftereffect manifested in the inhibition of salivary secretion on the food rejected stimuli (hydrochloric acid and others) 3-18 minutes after termination of rotation.

Accelerations in a caudocranial direction, all other conditions being equal, led to more expressed inhibition of salivary secretion from the period of the aftereffect up to a day.

In investigations of the effect of radial accelerations in a craniocaudal direction with a value of 5g and a duration of 20 seconds, conducted on dogs with fistulas by Bass, there was revealed inhibition of the periodic stomach contractions, which reappeared 1-1$\frac{1}{2}$ hours after stopping the centrifuge.

During the effect of large values of accelerations equal to 7g for 60 seconds in the same direction there was noted the complete loss of 1-2 periods of stomach contractions with more prolonged (1$\frac{1}{2}$-3 hours) recovery time; simultaneously with this there appeared the secretion of gastric juice. Repeated effects with intervals of 4-6 days led to marked adaptation; the increase of the force of the stimulus, however, again caused the loss of the periodic stomach contractions; with this there appeared "spontaneous" secretion.

Accelerations in the opposite direction (caudocranial) caused, other conditions being equal, more significant changes in the periodic activity. For comparative evaluation of these changes it is possible to indicate [204, 205], that the loss of periodic stomach contractions in dogs is revealed only under conditions of atmosphere rarefaction corresponding to a height of about 8000 m with a pressure of 266.9 mm Hg.

In experiments, conducted on dogs with isolated ventricles according to Heidenhain, i.e., ventricles deprived of parasympathetic innervation, it was established that accelerations in a cranicaudal direction with a value of 5-9g (20-60 seconds) cause inhibition of secretion up to 2$\frac{1}{2}$ hours after termination of rotation. Subsequently, the secretion of gastric juice attains initial level. For dogs with fistulas of the stomach according to Bass (with preserved normal innervation of the stomach) there is observed under equal conditions of experiment after short-term inhibition of secretion the appearance of abundant juice secretion.

An analysis conducted by us of actual data showed that stimulation of the secretion gastric juice is connected with the predominant influence of the parasympathetic nerves and, conversely, inhibition of secretion with the predominant influence of the sympathetic nerves

[226, 244].

Considerable shifts in the operation of the organs of the gastro-intestinal tract during accelerations have also been observed in people. Thus, during the action of accelerations in a craniocaudal direction with a value of 3-5g and a duration of 30 seconds, and also in the subsequent 5-10 minutes after stopping the centrifuge in people there has been observed a sharp inhibitory reaction of gastric secretion right up to its complete absence, even if the alcoholic breakfast according to Erman, which is a strong stimulus of stomach secretion, is used. The inhibitory reaction then was changed by the reaction to the increased secretion in 15-45 minutes. As compared to the control data juice secretion was increased by five times its value (Fig. 10).

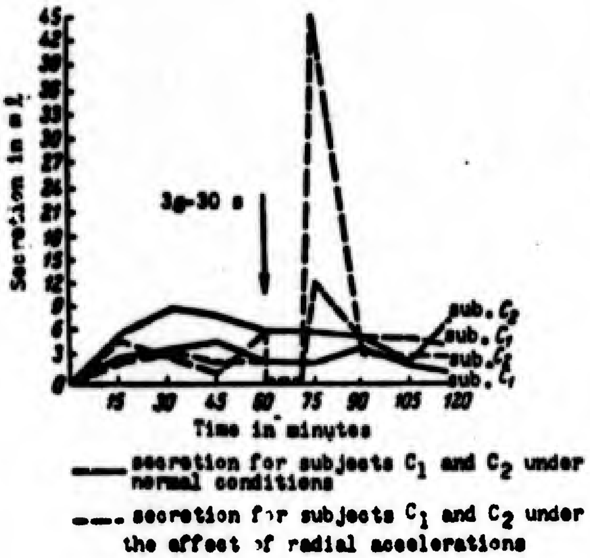

Fig. 10. The influence of radial accelerations on the secretion of the gastric glands.

It is interesting to note that if for animals during accelerations with a value of 3-5g and a duration of 30 seconds the periodic motor operation of the stomach was disturbed, then for people under the same conditions no essential changes were observed. This fact deserves special attention, since it is completely valid to assume that in a comparative-physiological aspect man is more resistant to the effects of accelerations [226, 244].

For dogs, operated on by the Tiri method, there was also studied the secretion intestinal juice and enzymes from the loops of the small intestine. After the effect of repeated accelerations in a cranio-caudal direction with a value of 5-9g for 20-60 seconds there was noted a tendency toward the lowering of juice secretion. In the subsequent 2-3 days the secretion increased by 2-3 times; the activity of amylase and alkaline phosphate was also increased. However, after a week the activity of the phosphate began to sharply decrease and subsequently for approximately a period of 4 months it was not possible to detect its restoration either under the condition of juice secretion by mechanical stimulus, or in periodic secretion. As regards the value of juice secretion, then after several days or weeks (depending upon the value of the accelerations) its restoration was observed up to the background level.

Accelerations in a caudocranial direction, other conditions being equal, lead to more expressed changes in the secretory activity of the gastric and intestinal glands. Accelerations in a caudocranial direction with a value of 3-5g (20 seconds) caused in dogs changes similar to the effects of accelerations in a craniocaudal direction with a value of 7-9g (20 seconds).

An analysis of experimental data revealed that the recovery time of the disturbed functions of the organs of the gastrointestinal tract as compared to the function of the organs of respiration (rate), cardiovascular system (pulse, electrocardiogram) and the central nervous system (electroencephalogram) takes place in an unusual manner and is delayed. The pulse, electrocardiogram, electroencephalogram, and others are usually restored under these conditions to the initial level in 3 minutes; for the salivary glands a short-term period of aftereffect is very characteristic, this is calculated in tens of minutes; for the gastric glands - several hours; but for the processes of intestinal secretion - weeks. It is obvious that the speed of restoration of the disturbed functions of the salivary, gastric and intestinal glands has a definite dependence on the inherent (to them) complex-reflex neurohumoral and trophic mechanisms of regulation. The most rapidly restored are those glands, the

the secretion of which is most intimately connected with the cortical actuating mechanisms of the central nervous system. In all variants of experiments the cortical actuating secretory mechanisms upon termination of rotation are preserved [242, 39, 226].

Inasmuch as in these investigations there were revealed new facts, making it possible to somewhat expend the concept of these mechanisms of regulation and compensation of functions during accelerations, so the works in this direction were expanded by us by the study of the secretory function of the pancreatic gland, and also of the periodic activity of the stomach and intestines.

At this stage of the investigations animals were subjected to the effects of transverse accelerations (chest-spine) with a value of 8g and a duration of 3 minutes. These parameters, according to literature, are used by many authors, therefore the results of investigations are comparable [123, 118, 87].

The periodic motor activity was studied with the help of ballooning (balloon-manometer) and roentgenological methods on dogs with fistulas of the stomach according to Bass. The time periods of work and rest served as indices and also the time of a complete cycle of periodic motor activity of the stomach and duodenum.

After the effect of the accelerations considerable deviations of the investigated functions were established. In one of the dogs there was observed continuous motor activity of the stomach and duodenum of the acid contraction type during the whole experiment (5-6 hours); for another dog the periods of "work" and "rest" were expanded in time, which led to the increase of the duration of the cycles periodic activity. On the 4th day in this dog there was observed continuous motilety, whereas in the other there were noted accelereated periods of "work" and "rest." On the day of the effect bile was poured into the stomach.

Increased gravitation caused (8g, 3 minute, chest-spine direction) disturbances of the coordination of the periodic motor activity of the stomach and especially of the duodenum; the aftereffect period - about 3 weeks. Along with these changes in dogs there were also expressed disturbances in the evacuation function of the gastro-intestinal tract, which consisted in accelerated evacuation of the stomach during the feeding by milk and deceleration during the feeding of meat, and also in the accelerated passage of the last portions of both meat food along the small intestine (65).

During transverse accelerations there were also established marked changes and in the processes of the secretion intestinal juice and enzyme formation. These changes were revealed, starting approximately at 4g, and the more intense were the effects, the sharper were the disturbances.

For dogs, on which there acted a single acceleration in the chest-spine direction at 8g for 3 minutes and the speed of increase of the overload was 0.2g per second, the secretion of intestinal juice from the intestinal loops was decreased in the first days after the effect. Subsequently, there appeared considerable fluctuations in the direction of hypo- and hypersecretion with a prolonged period of aftereffect of 8-9 weeks. Changes of the activity of enzyme started on the 3rd day: the activity of amylase, enterokinase and alkaline phosphate increased considerably and was maintained at a high level, different in duration of time for each enzyme; for alkaline phosphate the aftereffect period was approximately equal to 4 months (200).

During a single effect of acceleration in a craniocaudal direction with a value of 7g and a duration of 1 minute the changes in the secretion of juice and enzymes were similar to the dynamics revealed with a effect of single transverse accelerations with a value of 8g and a duration of 3 minutes.

In another series of experiments, where frequently and repeatedly there were applied different (in value and duration) transverse accelerations (3-5g - 3 minutes; 6g - 4 minutes; 8g - 3 minutes; 10g - 2 minutes; 12g - 1 minute), the disturbances in the secretory processes consisted in an increase of secretion of intestinal juice in the aftereffect right up to the appearance of continuous (spontaneous) juice secretion and the disturbance of enzyme formation. On certain days of the experiments individual enzymes (amylase, enterokinase, alkaline phosphate) did not appear in the intestinal juice and in the feces [200].

Sharp disturbances of the functions enzyme formation are also characteristic of other extreme effects (hypoxia, qualitatively diverse food regimes and others), on the basis of which a concept was formed about the fact that such a prolonged aftereffect on the part of the secretory processes of the intestinal glands is connected with the relative autonomy of their regulatory mechanisms. As is known, the actuating mechanism of intestinal secretion is basically contact, local, and neuroreflex [226, 233, 239].

Analysis of the data once again showed that the differences in the dynamics of the secretion of intestinal juice and enzymes under conditions of the effect of accelerations depend on the value, direction, duration, recurrence, and time intervals between the effects and other characteristics of the stimulus.

In the investigations of the dynamics of the secretion of pancreatic juice and its enzymes (amylopsin and trypsin) during chest-spine accelerations (8g – 3 minutes) there were also detected disturbances both in the juice secretion and in the content of enzymes in it. About this it was even possible to judge from the sharply changed appearance of the juice. Before the effect it had slightly opalesced and it did not contain dense impurities and after standing did not precipitate. In the first days after the effect there were noted a brownish hue and a turbidity of the juice; its viscosity was considerable and there were whitish flocs. Before the effect the content of protein was within the limits of from 6.8 to 10 mg/mℓ; after the effect – from 3.7 to 32.8 mg/mℓ.

Immediately after the effect of accelerations the amount of pancreatic juice was in definite dependence on the initial functional state of the gland. For some dogs after the first effect of accelerations there was observed a decrease of juice secretion, for others – an increase. Subsequently, for all dogs the secretion was considerably increased, and the fluctuations in the values of juice secretion had a phase character. Shifts were observed in the relationships between the complex-reflex and humoral-chemical phases of the secretory processes. The period juice secretion to food stimulus was extended, and after repeated effects of accelerations in a number of cases "spontaneous" secretion appeared.

Changes were observed and in the activity of the enzymes: the stablest was trypsin. However, in one of the dogs after the first effect the activity of trypsin sharply dropped and sometimes was not even detected at all. The activity of amylopin was increased. Changes in the activity of trypsin and amylopsin had, thus, a different directivity.

The duration of the disorders of juice secretion was $2\frac{1}{2}$ to 3 months; the enzyme secretory function by this time, as a rule, was not restored to the values of the initial level.

The character and depth of the secretory disorders were dependent upon the frequency of the effects of the given stimulus (accelerations) and time intervals between the effects. The greatest disturbances were established as a result of the repeated effect, performed 6 weeks after the primary effect. They led to sharper shifts both in the values of juice secretion and also in the content of enzymes in the juice. After the first effect the changes of the level of juice secretion fluctuated for various animals from -6% to +36%; after the second effect – from -12% to +148%.

With an increase of the time interval to 14 weeks the restoration of the indices of secretion to the initial background values was noted starting with the 7th week.

After the third effect of accelerations of the same intensity, to which 3 dogs were subjected 12 weeks after preceding effect it was noted that in one of the dogs the level of secretion was within the limits of the background indices. For two other dogs there was observed an increase of the secretory level, but it was less significant than after the second effect.

After the fourth rotation of the 2 dogs 12 weeks after the preceding effect the indices of pancreatic secretion were within the limits of the initial level (51).

Thus, it is possible to note that with an increase of the time intervals between identical (by their characteristics and intensity) effects of accelerations the disturbances in the processes of pancreatic secretion are considerably smoothed and normalized.

In a simultaneous study of the dynamics of the secretions of gastric and pancreatic juices it was noted, as a rule, that the graphs, characterizing the pancreatic secretion of juice, corresponded to the graphs of gastric secretion. Inasmuch as the basic amount of pancreatic juice is secreted under the influence of secretin liberated by hydrochloric acid getting into the small intestine, then it is possible to speak about the absence of disturbances in the regulator interconnections of these organs.

In the gastric, pancreatic and intestinal juices of these dogs we also studied the changes of activity of lysozyme [51, 200, 110, 250]. The dynamics of the changes of this enzyme differed sharply from the dynamics of the other investigated enzymes, which, obviously, is connected with its specific antibacterial properties and its physiological homeostatic role ensuring the metabolic processes as carried out by the microflora of the gastrointestinal tract.

A single action of overloads causes considerable changes in the bacteriological properties of the gastric juice in dogs. On the first day after the effect there was observed a certain increase of lysozyme activity, then the period of its deep inhibition arrived [the titer of lysozyme became equal to 1:332 instead of 1:860 in the period of the background). In individual periods the titer of lysozyme was 4-5 times lower than the initial values (on the 4th, 9th, 14th, and 18th day after the overloads the titers equaled 1:176, 1:159, 1:117 respectively). The period of the aftereffect equaled 23 days; after this the lysozyme activity was restored.

Under the influence of a single effect of acceleration (8g, 3 minute, chest-spine) on the first day the activity of lysozyme in pancreatic juice increased, subsequently (after 2-4 days) it sharply descended (by 5-7 times); the period of the aftereffect was 4-6 weeks (Fig. 11). Thus, before rotation of the dogs on the centrifuge

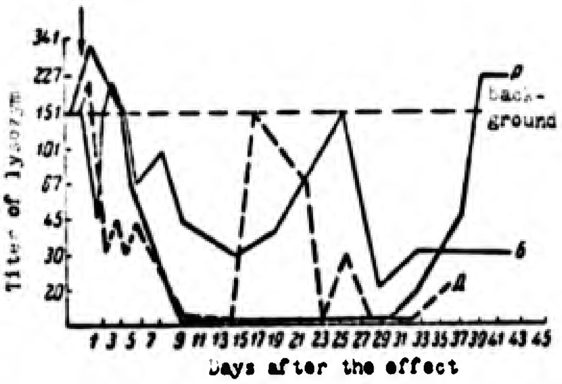

Fig. 11. Activity of lysozyme of the pancreatic juice during accelerations. 20 × 10.

the titer of lysozyme was equal to 1:101-1:151, and in the period of the aftereffect it descended to a level of 1:20. Similar changes were also established in the intestinal juice [110].

The lowering of the activity of lysozyme, obviously, is connected with the general lowering of immunological resistance of the organism as a result of extreme influence. This is caused not only by the attenuation of the antibacterial properties of the digestive juices, but also by the immunochemical changes of the internal environment of the organism. Actually it was shown that during accelerations with a value of 9g, created on the centrifuge, the absorbtive and digestive functions of the neutrophils were oppressed. The lowering of the antibacterial properties of the blood was also observed in dogs flying on a geophysical rocket and on the second sputnik-spaceship (the dogs Otvazknaya, Mushka, and Belka); the phagocytotic ability of the blood cells was restored 3-4 weeks after the flights [6].

During the experimental effects the bactericidal function of the skin also descends [144].

According to Parrot [367], lysozyme - a substance possessing especially high antihistaminic properties. It is approximately in 300 times more active from antihistaminic pharmaceutical preparations. Consequently, the lowering of the activity of lysozyme during accelerations can be accompanied by an increased amount of histamine in the tissues of the organism which will promote the appearance of allergic states, a change of vascular tonus, and the disturbance of the permeability of the histo-hematic barriers [81, 98, 383].

Changes of the activity of lysozyme were also established under the influence of other extreme effects. Thus, during the stay of the subjects in a hermetically sealed chamber there was also observed a marked lowering of activity of lysozyme. According to the degree of adaptation of the organism to the effects of accelerations (8g - 3 minutes with great intervals between the effects) the changes of the activity of lysozyme are normalized. After the fourth effect disturbances are not detected [110].

Structural-Functional Disturbances of the Digestive System During Accelerations and Hypoxia

The duration of aftereffect, established by us during accelerations, is in the most intimate way connected with the extremely complex structural reorganization in the individual tissues and systems of the organism. Here there appear, first of all, adoptive and compensator intersystem reorganizations frequently with the complete absence of parallelism between the functional and morphological disturbances of the individual organs. The latter can take place, for example, during an externally satisfactory general condition of animals and with relatively well preserved conditioned reflex reactions. Thus, in experiments on rats during multiple effects of accelerations conducted 120 times in one month (10g - 1 minute, head-pelvis direction, 4 effects daily with intervals of 30 minutes) profound disturbances were established in the tissues of the brain, heart, lungs, kidneys, and liver with relatively good preservation of the developed conditioned reflexes. Under these deliberately created rigid conditions the functional manifestations of cortical dynamics were in evident conflict with the morphological changes [242, 254].

As an example of the disparity between the overall functional state of the organism and the morphological changes of certain organs, especially of the glands of the body and of the fundus ventriculi, there can serve the data obtained by Yu. M. Lazovskiy [134] during a study of the influence on the organism of actue oxygen starvation. The stay of dogs at a height of 8000 m and exposure of 4-6 hours during stereotypic recurrence of ascents (every 1-2 days) led to the increasing breakdown of the structural elements of the mucous membrane of the stomach. There was observed an almost solid necrobiosis of the covering epithelium, necrosis of the individual arterioles, transformation of the chief and secondary cells into indifferent epithelium, etc. However, starting approximately with the 15th ascent, there began to be detected phenomena of regeneration up to complete restoration (63 ascents) those acute changes, which were accumulated during the preceding effects. Under equal conditions neither in the pyloric section of stomach, neither in the intestine, nor in the pancreatic gland were significant morphological changes observed. This testifies to the presence of potential, far-from-uncovered, compensator-adaptive resources of the organism. It is necessary to recognize that under experimental conditions the glands of the fundus and of the body of the stomach by virtue, obviously, of the neuroendocrine regulator role inherent to them are at first in a state of extreme functional stress and acquire sharply expressed pathological characteristics. These changes must be examined as individual, particular manifestations of the deep inhibition and selective vulnerability of the tissues and cells of some systems to ensure the preservation of the processes in the cerebral cortex, and also the normalization of the most vitally important systems, for example, respiration and blood circulation. It is possible to express a hypothesis about the fact that the glands of the fundus and of the body of the stomach are temporarily "sacrificed" to the whole organism and the pathological features acquired by them reflect to some degree that "value" for which the overall adaptive and compensator reorganization of the functions in the whole organism was carried out. During extraordinary (for the organism) circumstances new functional intersystem interrelations are established because of feedbacks and autonomous regulation. These interrelations balance the organism with the environment and also favoring the restoration of the mentioned structural, functional and metabolic disturbances in the glandular tissues themselves. In preserving the mechanisms of higher nervous regulation optimum conditions are created in the organism for restoring the mechanisms of nervous regulation on the lower levels, thanks to which the processes of reparative regeneration are also carried out.

Similar regulation and coordination of the functions of the organism were in their time noted by I. P. Pavlov, who wrote: "It would seem very surprising indeed, since it is (the central nervous system. — I. Kh) the most delicate, the most complex, and should be the first to break down; however, in certain cases the converse happens: the body gives out, and it continues its highest functions."[1]

It is necessary to recognize that under conditions of extreme influences the glands of the body and of the fundus of the stomach acquire, apparently, a special regulator role. This is also confirmed by the literature about the similar dynamics of the morphological disturbances in the cortex of the adrenal glands [352, 353]. Inasmuch as under conditions of hypoxia the structural changes of the glands of the body and of the fundus of the stomach coincide in time with the structural changes in the cortex of the suprarenal glands and have identical directivity, an assumption about the interlinked operation of not only these, but also of there glands of the neuro-endocrine system is possible.

A study of the influence of hypoxia on the function of the digestive glands revealed that oxygen starvation first of all has an effect on the nervous actuating mechanisms of regulation of the secretory processes. The more intimate the connection of the central nervous system and digestive glands, the more markedly does their activity change during hypoxia. Thus, for the intestinal glands

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[1]Pavlov media. T. III. Publishing House of Academy of Sciences of USSR. M., 1949, p. 289.

the "high-altitude threshold" is equal to approximately 8000 m, whereas for the salivary glands it is equal to 3500-4000 m [205]. However, "high-altitude thresholds" have a relative value, since during more prolonged exposures the low heights also can have a definite influence on the functional state of the digestive glands.

Pathomorphological changes in the gastrointestinal tract were determined by M. I. Razumov and I. M. Khazen under the influence of transverse accelerations with a value of 8g and a duration of 3 minutes [206, 248].

The changes in the secretory apparatus of the tabular glands of the digestive system are quite considerable. They are different in their character, localization and distribution in various sections of the stomach. In the prepyloric section and in the region of the body of the stomach two types of changes have been established. The first of these is characterized by the shift of the cells of the secretory epithelium of the tubular glands to the fundic end of these tubes: the chief and parietal cells are displaced. In the prepyloric section of the mucosa these displacements are more weakly expressed than in the region of the mucous membrane of the fundus of the stomach, where the displaced epithelial cells at the end of tubes are densely adjoin one another. Due to the displacement of the cells the structure of the tubular glands is disturbed, and they are assembled in parcels, filled with deformed chief and parietal cells.

The other type of disturbances is characterized by the destruction of the tubular glands, which turned out to be devoid chief, parietal, accessory and prismatic cells of the epithelium.

In the prepyloric section of stomach the changes are expressed to a lesser degree - in the convoluted part of the tubular glands the epithelium was preserved; the cells of the cylindrical epithelium, the cytoplasm of which is elongated along the longitudinal axis of the cell body during distension of an intercellular fissure and in pyknosis of the nuclei, are deformed.

In dogs, killed on the 2nd and 3rd day after the effect of the accelerations, among the flattened cells of the epithelium of the tubular glands under high magnification there are encountered signs of karyokinetic division.

In the submucosa layer of the mucous membrane of the stomach there are seen venous vessels highly dilated and overfilled with erythrocytes. Also highly dilated are the lymphatic vessels, in which the lymph contains an admixture of erythrocytes (lymphostasis).

In investigating the mucous membrane of the stomach of dogs, killed 7 days after the effect of accelerations, there was detected the formation in the tubular glands of the stomach of cellular syncytium; on the 15th day the syncytium was converted into differentiated parietal and chief cells, taking the location inherent to them.

In individual sections of the mucous membrane of the small intestine there were clearly expressed circulatory disorders in the circulatory and lymphatic vessels (Figs. 12, 13, and 14).

Fig. 12. Duodenum. Dyed with hematoxylin-eosin. 20 × 10. The day after the effect of accelerations. In the villus is seen edema of the stroma. The central lymphatic duct of the villus is highly dilated; the escape of erythrocytes from the capillaries into the edematous stroma is evident.

Fig. 13.

Fig. 14.

Fig. 13. Duodenum. Dyed according to Hotchkiss with red hematoxylin. 10 × 10. The day after the effect. The central lymphatic ducts of the villi are highly dilated by the chyle accumulated in them. In the composition of the chyle there is shown glycoprotein, colored bright-red on the preparation. The stroma of the villi is swollen.

Fig. 14. Duodenum. Dyed with hematoxylin-eosin. 10 × 10. The day after the effect. The base of the villi is presented in an oblique microscopic section (cut). The central lymphatic ducts are dilated with chyle.

In some sections of the mucous membrane the lymphatic vessels on the villi are somewhat dilated and filled with chyle, in others — the villi are edematous and their central lymphatic ducts are expanded to the limit and are ruptured by the accumulated chyle; the central veins are overfilled with erythrocytes, evident are hemorrhages arising from rupture of the capillaries and venules (Fig. 15). The epithelium covering the cryptal tubules showing lesions in the form of nuclei displacement; the latter are displaced in the fundic end of the cryptal tubules show lesions in the form of nuclei displacement; the latter are displaced in the fundic end of the cryptal tubes, where they form disorderly accumulations.

Fig. 15. Duodenum. Dyed with hematoxylin-eosin. 10 × 10. Near the base of the villi of the glandulae duodenales section everywhere there are seen hemorrhages and chyle stasis. Edema of the stroma separates the tubules of the glandulae duodenales.

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In investigating the mucous membrane of the intestine at later periods (on the 7th and 15th day) after the effect there are revealed traces of hemorrhage in the reticular stroma of the cryptal section of the mucous membrane of the small intestine, and also dilation and deformed central lymphatic ducts of the villi. In the fundic section of the crypts there is observed disorderly accumulation of the displaced nuclei of the epithelium.

It is especially necessary to emphasize that the described changes do not have a diffuse character all along the intestine. In certain sections of the small intestine the normal structure of the mucous membrane will be preserved. In the section of the intestine, taken for analysis of the average sections of the small intestine, and also of the sections of the anterior section (at a distance of 20 cm from the duodenum), changes rarely detected or are completely absent (Fig. 16).

It is necessary to note that in individual cuts through the whole cross section of the intestine the changes are localized only in one side of the intestinal wall, whereas in the opposite wall they are not noted.

Fig. 16. Anterior section of small intestine. 10 × 10. Dyed according to Hotchkiss with red hematoxylin. The day after the effect. Uninjured section: circulatory and other disorders are absent.

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The presence of changes in some sections and their absence in others, obviously, is connected not only with the functional peculiarities of the different sections of the organs of digestion, but also with those conditions, in which the individual sections of the intestine find themselves during the effect of accelerations – on the degree of filling of the lumen of the intestinal loops, on their mobility in connection with the length of the mesentery, possibly, on the presence of gas bubbles.

On preparations of the pancreatic gland, obtained from dogs, killed 3 hours after the effect of accelerations, in the cells of the acinous epithelium there were no noticeable hystological changes. Also there were no circulatory disorders of the blood vessels. Moreover, in the interlobular secretory ducts of the gland there was observed a displacement of the epithelial cells, covering the ducts and deformation of the cellular cytoplasm and pyknosis of the nuclei were evident. In the lumen of the ducts there is no secretion produced by the acinous cells (Figs. 17, 18, 19, and 20).

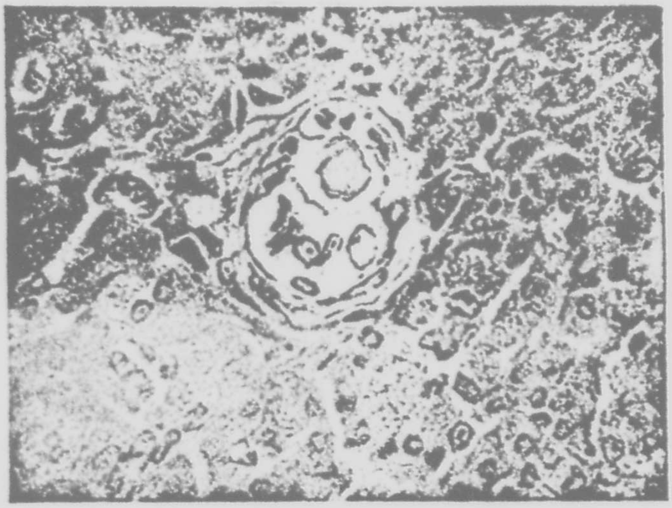

Fig. 17. Pancreatic gland. Dyed with hematoxylin-eosin. 60 × 12.5. Three hours after the effect. The interacinous secretory duct in cross section; the epithelium of the secretory duct is in a state of disintegration; in the lumen a small quantity of eosinophilic secretion is observed; the granularity of zymogen is preserved.

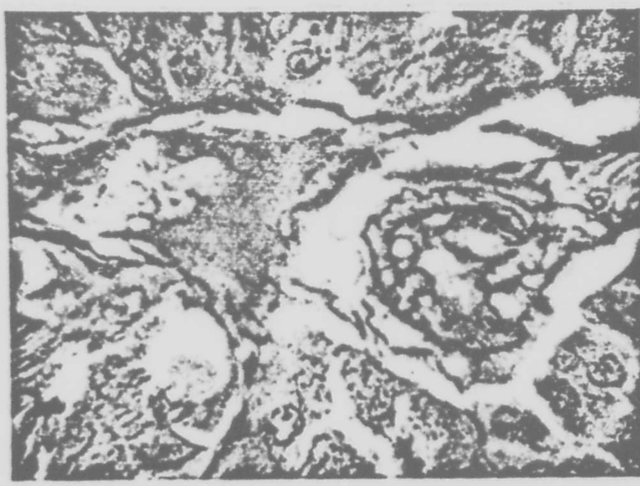

Fig. 18. Pancreatic gland. Dyed according to Hotchkiss with hematoxylin. 100 × 12.5. Three hours after the effect. The interlobular secretory duct is shown with the vein into the cross section. In the secretory duct — tearing away of the covering epithelium and pyknosis of the nuclei. In the vein — symptoms of stosis and separation of the plasma from the erythrocytes (the dark coloring — the plasma and erythrocytes are not colored. On the preparation the plasma has a bright raspberry color characteristic of glycoproteins of the blood).

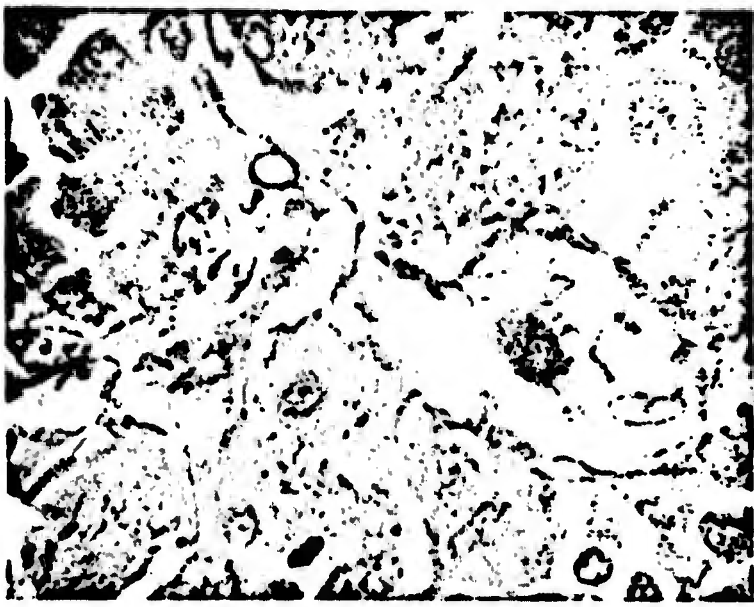

Fig. 19. Pancreatic gland. Stained according to Hotchkiss with hematoxylin. 100 × 12.5. Three hours after the effect. The interacinous secretory duct; displacement of the nuclei of the epithelium of the duct and their sharp swelling. The acinous cells have rounded cytoplasm; zymogen granulation is located in the intercellular fissures.

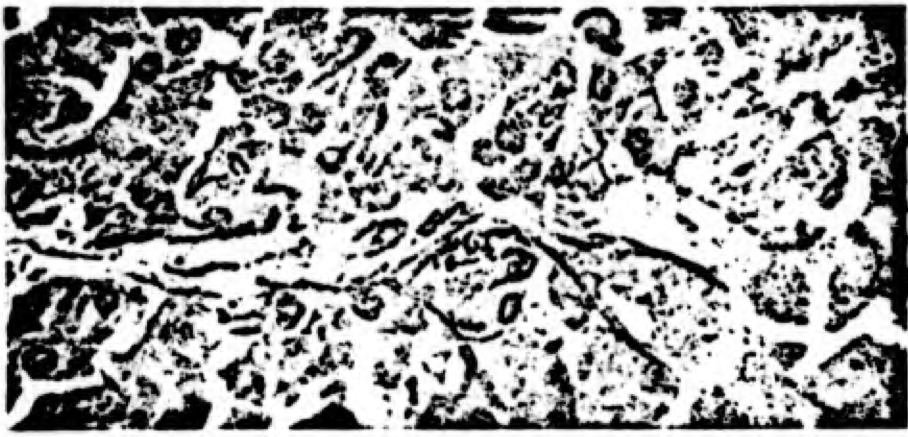

Fig. 20. Pancreatic gland. Nuclei stained with hematoxylin. 100 × 12.5. Three hours after the effect. The longitudinal cross section of the intracinous secretory ducts and their fall into the interacinous duct. The epithelium of the ducts has sharply swollen nuclei. In intracinous section the epithelium is displaced, in places destroyed.

On the 2nd day after the effect there was detected a small accumulation of secretion in the tubules of the Golgi apparatus. In the reactions according to the Hotchkiss method in the composition of the secretion there is detected a polysaccharide component. In the lumens of the interlobular secretory ducts secretion is not detected. In the lymphatic capillaries of the gland there are seen symptoms of lymphostosis.

On the 3rd day the secretory function of the acinous epithelial cells was restored. But due to the damage to the epithelium of the secretory ducts the outflow of the secretion was hampered as a result of which it accumulates and the lumen of the ducts is distended. The secretion also accumulates in the intercolory sections of the secretory ducts, in the acini. There are encountered sections showing eruption of the secretion into the reticular stroma of the gland. In the composition of the secretion there is contained an increased quantity of the polysaccharide component (Fig. 21).

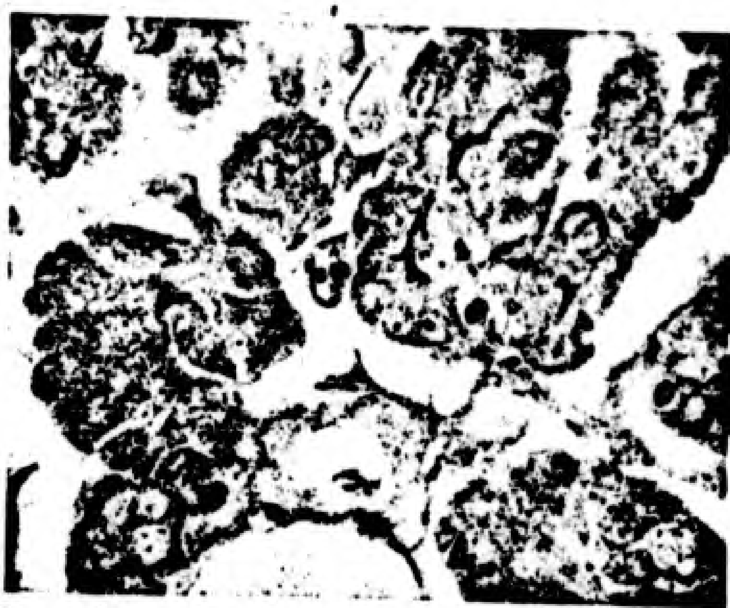

Fig. 21. Pancreatic gland. Stained according to Hotchkiss with hematoxylin. 40 × 20. Third day after the effect. The acini of the gland are opened. The secretion of the acinous cells accumulated in the lumen of the acinous due to impeded efflux.

In dogs killed on the 5th and 7th day after the effect there is observed the restoration of the efflux of the secretion from the acini and the intralobular ducts.

Due to the massiveness of the abundant blood supply and the semimobile position in the abdominal cavity in the liver under conditions of the effect of accelerations, obviously, there appear complex and unique disturbances. Therefore, we attached in our work great importance to a broader analysis of the changes appearing during accelerations in the epithelium, and also in the Kupffer cells of the liver.

In a dog killed 3 hours after the effect, the tissues of the liver were highly swollen, the blood capillaries of the liver lobules were distended. In the cytoplasm of the Kupffer cells there are found eosinophilic granules, and in the reaction according to Hotchkiss clumps colored raspberry color, but giving a negative reaction according to Steamen. In the reaction according to Gol'dman for the detection of phenoloxydose the increase of its activity appeared in the cytoplasm of the Kupffer cells located in the peripheral sections of the liver lobes and the interlobule zones.

The cells of the liver epithelium had rarefied cytoplasm palely colored with basic dyes. In an unusually large number there were detected binuclear cells of the epithelium, which are more frequently encountered in liver beams of the internal sections of the lobules, near the central veins. Here there were rarely observed cells, in the cytoplasm of which was distributed 3 nuclei each. In the cytoplasm of the liver cells the nuclei were disposed eccentrically close to the cellular membrane. Among them there were encountered some that were increased in volume. The diameter of the nuclei of the cells of the epithelium of the liver of control dogs equaled 4.2-5.0 microns, the experimental dogs (3-7 days after the effect) - 6.3-7.3 microns.

For a dog, killed one day after the effect there were observed in the liver the same changes of the vessels and cells of the epithelium. Furthermore, in the cytoplasm of the Kupffer cells during the reaction according to Perls there was detected an amount of trivalent iron, and in small sections of the capillaries of the peripheral sections of the lobules - lipids which saturated the cytoplasm of the Kupffer cells. In the cytoplasm of the cells of the epithelium of the central sections of the lobules there was noted fine-drop adiposis. The septal lymphatic vessels were highly distended, in the lumen - homogeneous mass of protein, in the composition of which there were detected glycoproteins.

In the cytoplasm of the Kupffer cells of the animal killed 3 days after the effect in places there appeared drops of neutral fat. In the cells of the liver epithelium there was detected fine-drop adiposis. In the nuclei of many cells of the epithelium of the liver trabeculae there were traced inclusions in the form of brilliant, highly light-refracting crystals of prismatic form. The epithelial cells containing nuclei with crystals were encountered dispersed in the internal sections of the liver lobules, near the central veins (Fig. 22), rarer – in the peripheral sections. The nuclei containing protein crystals had the dimensions: transverse axis – 6.3 microns, longitudinal – 12.5-13 microns.

Fig. 22. The third day after the effect of the accelerations. Microphotograph of the internal section of a liver lobule. Stained with hematoxylin-eosin. Magnification oc. 40, ob. 12.5. 1 – displacement of the nucleus of the cells of the epithelium. Deposition of oxyphilprotein in the nuclear substance in the form of prismatic crystals. The capillaries of the lobule are distended.

In all forms of fixation of the preparations there were noted crystal inclusions in the nuclei of the epithelial cells, in paraffin, frozen and celloidin microscopic sections. They did not dissolve in a water medium, ethanol, acetone and xylene, and in staining with eosin along with the erythrocytes there appeared oxyphile. In polarized light double refraction was not noted.

There were no polysaccharide components and lipids in the composition of the crystals.

In formulating the reaction according to Fel'gen in the crystals there was detected neither [DNA] (ДНК) nor [RNA] (РНК). In the reaction according to Bonkheg there was revealed the protein nature of the crystals. In the individual nuclei of the liver cells there were seldom encountered crystals arranged in pairs, lying parallel to each other (Fig. 23a). The prisms in the cross section had a trihedral or a tetrahedral form. Frequently in the cytoplasm of the epithelial cells there lay two nuclei, of which only in one did crystal protein precipitate (Fig. 23b). In other cells both nuclei contained protein (Fig. 23c).

Fig. 23. Third day after the effect of accelerations. Microphotograph. Stained with hematoxylin-eosin. Magnification: oc. 100, ob. 15. Cells of the epithelium of the liver. a) binuclear cell. In one of the nuclei there are contained two eosinophilic crystals, located parallel to each other; b) the barrel-shaped form of the nucleus of the epithelial cell, the membrane of which is distended by the growing crystal; c) binuclear cell of the epithelium; in one of the nuclei there is contained a formed crystal, in the other nucleus there is the initial manifestation of precipitation of eosinophilic protein. The chromatin is concentrated near the nuclear membrane; 2 — the nucleus of the epithelial cell is increased in size, it has a clearing in the center of the nuclear substance.

The volume of the body of the affected cells of the epithelium increased, their cytoplasm became rarefied and was weakly dyed. Under large magnification of the preparations it was possible to detect displacement of the nuclei beyond the limits of the cellular body (Fig. 24).

Fig. 24. Third day after the effect of accelerations. Microphotograph. Stained with hematoxylin-eosin. Epithelial cells of the liver. Magnification: ob. 100, oc. 15. 1 — binuclear cell. Both nuclei are displaced, one of them contains an eosinophil crystal; 2 — nuclei of Kupffer cells; 3 — mononuclear cell, in the nucleus of which is a crystal.

The study of the growth of crystals in the nuclei of the epithelial cells of the liver upon the appearance of transitional changes in the structure of the nuclear substance showed that the initial symptoms of the disturbance of the structure were expressed in a reorganization of the nuclear chromatin and an increase in the volume of the nucleus. It became barrel-shaped; the chromatin and the nuceolus moved towards the nuclear membrane, and in the cleared central part of the nuclear substance there appeared an oxyphilic substrate. In this period in the reaction according to Fel'gen it was revealed that DNA is distributed in a massive ring near the nuclear membrane and a growing crystal surrounds the thinner layer. Between both rings was a light space (Fig. 25). The further increase of the composition of the nuclear substance of the protein substrate

Fig. 25. The third day after the effect of accelerations. Nuclear reaction of Fel'gen. Epithelial cells of the liver. Magnification: ob. 100, oc. 15. Among the damaged nuclei there lies an increased in size, epithelial nucleus. In the center of the nucleus there is formed a protein crystal. The DNA of the nucleus is detected near in the form of a ring and a thin layer around the crystal.

led to the formation of a prismatic structure. The crystals lengthening, stretched the nuclear membrane, the form of which became cigar shaped. In a completely developed crystal the length exceeded by 4-5 times the diameter of a normal nucleus of a cell of the liver epithelium (see Fig. 23a). Upon becoming a crystal of well-developed form the amoung of DNA in the nuclear substance decreased. Upon its complete disappearance the nuclear membrane ceased to be detected, and the protein structure of the crystal became distended (Fig. 26).

Upon formation of lipids in the microscopic cuts of the liver there was detected the precipitation of cholesterol in the cytoplasm of the individual liver cells located in the peripheral sections of the lobules. There not many of these epithelial cells; they had a denser, light-refracting cytoplasm, stained basophilically.

Fig. 26. The third day after the effect of accelerations. Nuclear reaction of Fel'gen. Magnification: ob. 60, oc. 10. Atropy of the damaged cells. Swollen protein crystals - traces of the atropy of the cells.

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In the liver of animals killed on the 7th, 15th and 30th day after the effect of acceleration, in the liver lobules there appeared cell; nuclei with protein-crystal inclusions in only 2-3 cells of the epithelium of the hystological cut. There were more frequently encountered nuclei with lucid nuclear substance in the center and chromatin on the edges. Traces of disintegration or necrosis of the cells were not evident. The nuclei of the epithelial cells under different magnifications had an unequal volume: some - somewhat increased, others - decreased, with lateral drawing in of the nuclear membrane and with more intensively stained chromatin.

In a remote aftereffect of acceleration on the epithelial cells of the liver of an animal killed on the 30th day there was detected fatty infiltration. The cell nuclei lay eccentrically in the cellular body, and fatty drops of average size occupied the central sections of the cytoplasm. Fatty depositions occupied all the cells of the liver trabeculae in the lobules. Against a general background of fatty infiltration in the composition of the liver lobules there appeared small groups of epithelial cells or individual cells, in the cytoplasm of which there were disposed numerous crystals of cholesterol, appearing brightly in polarized light. The cytoplasm of the cells was thickened and basophilic; it refracted light highly and did not contain drops of neutral fat. During the abundant accumulation of cholesterol in the cells their cytoplasm flaked and the nuclei became wrinkled.

In a study of the connection of these epithelial cells with the capillaries of the louble it was ascertained that the epithelial cells secreted from their cytoplasm a protein secretion containing cholesterol in the direction of the Kupffer cells. The latter absorbed it and secreted it into the lumen of the capillaries. In certain lobules the protein secretion also filled the lumen of the central veins. On the preparations it was evident that the nuclei were damaged there, where in the liver lobules the epithelial cells occurred in narrow fissures between the capillaries flowing into the central vein of the lobule. Apparently, in the period of the effect of accelerations during the rapidly increasing distension of these capillaries under the influence of the wave of blood circulation the cells experienced compression, as a result of which between the injured nucleus and cytoplasm the course of intracellular metabolic processes was disturbed. Moreover, obviously, there occurred a reorganization in the course of intracellular protein synthesis inherent to the epithelial cells of the liver, in consequence of which the synthesized protein was deposited in the nucleus itself and, accumulating, formed a crystal structure. The latter, expanding stretched the nuclear membrane to the limit, causing as a final result atrophy of the nuclear apparatus.

Nuclei with inclusions of protein crystals, and also their still noncrystalline precursors were detected in microscopic sections of the liver from the 3rd to the 30th day after the effect. They served as a characteristic symptom of the effect of an organism of accelerations of a specific intensity.

Undoubtedly, the origin of the successively developed disturbances of the metabolic process in the cells of the liver depended not only on the direct influence of the mechanical forces on them, damaging the intracellular structure. The changes of the structure of other organs and tissues of the organism under the effect of acceleration also had an effect. Here, undoubtedly, there must be attributed the overloading of the Kupffer cells in the first 3 days after the effect with the products of erythrocytic disintegration. It is also possible that the lesions in the cells of other organs and tissues of the organism are accompanied by the liberation into the blood of biogenous amines, which, proceeding with the blood stream into the capillaries of liver, are the specific exciters of the synthesis of phenolase in the cytoplasm of the Kupffer cells. Its activity very strongly increased on the 1st and 2nd day after the effect of acceleration on the organism of animals. Under the influence of accelerations the content of histamine in the gastro-intestinal tract increases considerably which, apparently, it is possible to examine as a component of the homeostatic system, promoting regeneration of damaged tissues. According to contemporary concepts similar properties [392] are inherent to histamine.

CHAPTER V

STRUCTURAL-FUNCTIONAL DISTURBANCES OF CERTAIN SYSTEMS OF THE ORGANISM DURING THE INFLUENCE OF EXTREME FACTORS

Under the conditions of flight on contemporary aircrafts the flying personnel is frequently in a state of great emotional stress which is connected with the responsibility, the specific character and the complexity of operations carried out in extraordinarily short intervals of time. The emotional stress accompanied by a sharp increase of the rate of respiration and of cardiac contractions can in certain cases cause as a result of hyperventilation a deficiency of carbon dioxide, a volume of sugar in the blood, and also an inadequacy of oxygen utilization by the tissues of the organism, and primarily by the tissues of the brain. The deterioration of the use of oxygen by the tissues also occurs under the influence of the action of accelerations and other extreme stimuli. Thus, for example, it is known that under the influence of transverse accelerations of 8g – 3 minutes there was noted a lowering of the saturation of the arterial blood with oxygen by 25%, and during breathing of 100% oxygen – by approximately 15%. During accelerations a drop of pO_2 is also noted directly in the tissues of the brain and heart.

In healthy people subjected to the effects of accelerations in a chest-spine direction from 4 to 6g with a duration of 1-3 minutes there were established extensive pulmonary arteriovenous anastomoses. This compensator-adaptive act, even during the breathing of pure oxygen, does not prevent the lowering of the process of oxygenation of the blood with oxygen. As a result of the increase in weight of the blood and the intrathoracic organs, and also of the circulatory disturbances in pulmonary circulation and of the disturbances of the mechanisms of gas exchange pulmonary atelectases appear [362]. The view is expressed that a similar arterial hypoxia as a result of pulmonary atelectasis and stretching of their upper sections can develop in man in the launch period and during the passage of the ship through the dense layers of atmospher on its return to earth [399].

Obviously, the problem of increasing the resistance of the tissues of oxygen deficiency, especially the problem of tissue adaptation, is acquiring paramount significance also in solving problems connected with the increase of the resistance of the organism to accelerations, rapid decompression, radiation, and other factors of flight.

The manifestation of structural disturbances during accelerations is in definite dependence not only on the specific peculiarities of the action of the stimulus (value, duration, frequency, direction, etc.), but also on the functional state of the organism.

The human organism and the highest animals during the whole period of evolution have adapted to the conditions of terrestrial gravitation. A considerable increase of gravitation, as well as its lowering, can be examined as extraordinary (according to force) physiological stimuli.

The mechanism of the action of accelerations is complex and first of all changes in hemodynamics are detected. During considerable (in magnitude) accelerations there also appear symptoms of circulatory hypoxia [111] which aggravate the action of the mechanical forces. Inasmuch as different tissues or organs of the entire organism possess different sensitivity and resistance to hypoxia, then thereby to some extent there will be determined the total response reaction of such tissues and organs during accelerations, especially in the after-effect period.

One of the first and most characteristic manifestations of the effect of accelerations is the disturbance of the permeability of the vascular wall. To this there testifies first of all the egress of formed elements per diapedesing which is also characteristic for acute hypoxia. As was already indicated, accelerations cause the appearance of hypoxic states and, consequently, under certain conditions and for certain stages accelerations and hypoxia act jointly.

Acceleration causes redistribution of the circulating volume of blood. Moreover its greater part accumulates in those parts of the body or organ, which experience the maximum effect. Under conditions of acute experiment of dogs (morphine-pentobarbital narcosis) the effect of transverse accelerations in a chest-spine direction leads, starting from 4g – 1 minute, to a minor (on the average 4%) decrease of oxygen saturation of the arterial blood. During an acceleration of 6g the level of oxygen saturation of the arterial blood began to drop 10 seconds after achieving this value and rapidly attained the average of saturation, equal to approximately 78%. The return to the initial level during a 3-minute rotation was completed approximately 80 seconds after stopping of the centrifuge. The drop of oxygen saturation of the mixed venous blood arrived after the changes of the arterial blood, but was considerably greater. The breathing of pure oxygen inhibited, but did not completely remove oxygen deficiency. The assumption was made that the decrease of saturation of the blood with oxygen occurs in connection with pulmonary arteriovenous shunting, caused by atelectasis of sections of the lungs. In its turn the level of atelectasis depends on the dorsal-ventral dimensions of the lungs and on the value of acceleration. That circumstance is significant that under different conditions of the effect of accelerations impairment of pulmonary ventilation was not observed [283].

V. G. Yeliseyev [87] established that during accelerations (8g – 3 minutes, chest-spine direction) in experimental animals – dogs, apes – there appear morphological disturbances in the tissues of the brain, spleen, lungs, kidneys, and the pancreatic gland. The basic changes in the pancreatic gland are connected with the derangement of blood circulation. In the early periods after the effect of the accelerations in the parenchyma of the organ there are observed definite degenerative-dystrophic changes. In individual sections of the interlobule arteries and arterioles there are detected symptoms of plasmorrhagia, accompanied by vacuolization and desquamation of the endothelium. Complete restoration of the pancreatic gland is attained towards the 30th day [117].

However, on the part of other organs there is observed a more prolonged aftereffect. In this respect the results of a study of the histostructural disturbances of the pulmonary tissues deserve serious attention. On the first day after the effect of accelerations there were observed polyemia, intumescence of the interalveolar septula and activation of their septal elements; there were observed atelectases and hemorrhages both by dispedesis, as well as a result of the rupture of blood vessels. In the region of the hemorrhages there are detected ruptures of the elastic fibers of the interalveolar septula. In subsequent periods there was noted the development of inflammatory symptoms in the pulmonary tissue, and in later periods (15-60 days) – focal sclerosing of the parenchyma as a result of earlier existing hemorrhages or the possible outcome of pneumonia.

It is especially necessary to emphasize that the described changes do not essentially affect the functions of external respiration, which reflects by itself, apparently, sufficient compensation [119].

In these experiments there was also revealed the noncorrespondence between the indices of external breathing and its structural disturbances.

Expressed pathomorphological disturbances in the tissues of animals (mice and guinea pig) carrying out a flight on a spaceship, were ascertained by V. G. Petrukhin [188]. In almost all organs (the brain, lungs, heart, liver, a fragment of the liver with the pancreatic gland, kidneys, suprarenal glands, spleen, testes, thymus) there were found essential changes of different character depending upon the periods elapsed after the flights.

Thus, in animals killed 2 days after a flight, there were residual phenomena of circulatory disorder. Considerably greater changes were observed in the ganglionic cells. The ganglionic cells of the occipital lobe and the region of the gyri centralis in the cerebral cortex are most frequently subject to changes; ten days after a flight the ganglionic cells were in different stages and forms of dystrophy; towards the 30th day the number of affected cells decreased; residual phenomena were also observed towards the 60th day. The structural disturbances of the liver also were restored towards this time. Such in general, according to a morphological analysis of the tissues of the brain and liver, is the period of aftereffect for animals subjected to the effects of factors of the environment under the actual conditions of space flight. Along with this V. G. Petrukhin [189] notes that in the tissues of the remaining organs (kidneys, intestines, pancreatic gland, and others) there were only observed phenomena of circulatory disorder, which vanished towards the 3-5th day.

In our investigations conducted on dogs under conditions of the effect of transverse accelerations (8g - 3 minutes), there were also detected pathomorphological changes of the internal organs (lungs, heart, kidneys, suprarenal glands, liver, stomach, small intestine, pancreatic gland).

In the kidneys and myocardium there is the manifestation of plasmorrhagia from the capillaries. In the myocardium there are observed phenomena of lymphostasis; moreover, the lymph in the distended capillaries contains an increased amount of protein bodies and polysaccharides. In the muscular fibers of the myocardium there is detected the disappearance of grains of glycogen.

In the kidneys, besides the plasmorrhages more extensive than in the myocardium, there are observed hemorrhages in the cortical substance. These circulatory disorders are revealed in animals killed on the 1st, 2nd, and 3rd day after the effect. Their traces are also revealed on the 5th and, less, on the 7th day after the effect.

In all probability, the structural disturbances to one or another degree in the individual functional systems during accelerations are also inherent to the human organism. Concerning this it is possible to judge at least on the basis of long known skin petechial manifestations revealed under conditions of the effect of the same physical characteristics of accelerations [38, 88]. During experiments on the centrifuge petechial hemorrhages on places with the least counterpressure it is possible to examine as a reflection of the overall disorders of blood circulation. In investigations conducted on volunteer subjects (there were used various-directed accelerations from small to the maximum endurable in magnitude and time of effect) there were determined the phase changes of vascular tonus, mainly the diastolic pressure and the caliber of the arteries and veins of the retina.

During aftereffect hypertension was detected in orbital (eye socket) artery, which had a marked regional character, just as its opposite, hypotension. The retinobracial index changed pathologically. A sharp regularity with an increase of qualitative changes appeared during the effect of accelerations up to 14g. During large values individual distinctions sharply appeared. Residual reactions in the form of distension of the caliber of the veins of the retina up to 170 microns (the norm is 125-155 microns) were observed during the course of 11 days after the effect of the accelerations. Along with this there also appeared hemorrhages in the conjunctiva of the eyelids, the eyeball, the retina; in certain persons 24-35 hours after rotation there were observed along the path of the main vessels of the retina large hemorrhages [88].

The presented materials show that the changes in the secretory and motor activity of the organs of the gastrointestinal tract are connected with the pathomorphological disturbances of various tissue structures of not only the digestive, but also of other systems of the organism. Consequently, for judging the functional state of the organism and the course of its adaptation to the effects of increased gravitation, and also to other extreme stimuli there have to be considered all reactions of the aftereffect of those functional systems, which give an idea not only about the accumulated (under the influence of one or another stimulus) intersystem interconnections and about the conditions of the correlation of the function of the entire organism, but also about hidden effects of the influence of stresses in the absence of acute reactions [247, 248, 249]. With such approach it is possible to judge about the regularity of the course of complex adaptational and compensator processes, by which the unity of the structure and function of the entire organism is determined. Disturbance of this unity - direct path to pathology.

The results of the described investigations of hypoxia show that those or other disturbances in the state of the organism during accelerations just as during certain other extreme effects, for example rapid decompression, are considerably smoothed with the presence of many day intervals between the repeated effects [203, 205, 233]. The establishment of intervals of time should be based on the actual analysis of all peculiarities of the aftereffect, also including its duration. The shorter the aftereffect the faster are restored those or other disturbances to the initial level, and the more reliable is the judgement about the resistance of the organism to the acting stimulus. However, the idea about the original functional state should be formed on the basis of integral indices, and not on information about the state of certain functions.

Thus, even during one-time-acting extreme effects there can be observed selective pathological disturbances in the individual functional systems, indicating a deficiency or exhaustion of nervous and neuroendocrine regulator systems.

Giving great value to these mechanisms of regulation of the relative constancy of the internal environment of organism, we raised the problem of ascertaining the formed (as a result of the extreme effects) relationships between the different biologically active substances - acelytcholine, histamine, adrenaline, noradrenaline, and also recently included in the circle of the investigations serotonin, inasmuch as its formation and metabolism in a very intimate way are connected with the digestive system.

The synthesis of serotonin is carried out mainly by the chromaffin cells of the gastrointestinal tract. It is also formed, furthermore, in the cerebral tissue with the assistance of the enzyme 5-hydroxytryptophan decarboxylose from initial product 5-hydroxytryptopan.

In its free form serotonin is subjected to oxidative deamination by the enzyme monozmine oxidose and is converted into the end product of its metabolism - 5-hydroxyindoleacetic acid, which is excreted with the urine. This way of inactivating serotonin is not the only one, but nonetheless it is acceptable to consider that according to the amount of excreted 5-hydroxyindoleacetic acid with urine it is possible to indirectly judge the intensity of serotonin metabolism in the organism [56, 182]. During the stability of the water balance of the organism the changes in the content of serotonin in the blood correspond to the changes of excretion of 5-hydroxyindoleacetic acid [373] with the urine.

Serotonin is an endogenous regulator of the tonus of the gastrointestinal tract. It has been established that serotonin or a substance close to it participates in the mechanism of the inhibition of the motor system of the stomach on the part of the mucous membrane of the duodenum [343]. Each section of the digestive tract is characterized by a specific gradient of reaction to serotonin. Starting with the duodenum the sensitivity to it decreases; in the iliac intestine motor reaction is more rarely observed than in the upper sections, and in the large intestine it is practically absent [301]. The greatest sensitivity to exogenous serotonin belongs to those sections of the intestine, in which there is relatively more endogenous amine [370]. Since the stimulation of the motor system is detected during the absence of simultaneous changes on the part of respiration, pulse and blood pressure, there is expressed the point of view about the fact that the organs of digestion are the most sensitive to serotonin [339]. There exist data about its content in the pancreatic and intestinal juices [250, 251].

According to N. N. Lebedev, there is a definite connection between serotonin and secretin. The liberation of serotonin causes a quickening of the rhythm of periodic activity as a result shortening of the periods of rest. The latter, however, do not only depend on the action of endogenous serotonin. The changes of rhythm can also be attributed to the influence of the adrenergic mechanisms [136]. The content of serotonin in the tissues of the digestive system changes under the influence of starvation and other effects [280]. During accelerations, especially in the period of the aftereffect, there was established a considerable increase of in the content of serotonin in the pancreatic juice (up to 2-2 1/2 times) in the absence of the content in it of 5-hydroxyindoleacetic acid [51, 250, 251]. Serotonin is also examined as one of the essential endogenous factors, rendering a stimulating influence on mitotic activity in the processes of regenerating the liver [201] and pancreatic gland. Six hours after an injection of serotonin the mitotic index of the gland exceeds by 33 times the mitotic index of the parenchyma of the organ of intact animals [215]. The given data are of indubitable interest in analyzing the mechanisms of reparative regeneration of the tissues [134, 135], during hypoxia, accelerations, and other extreme effects. Moreover, it is very important to consider the interconnection between serotonin and histamine.

It is known that during hypoxic states, radiation, traumata, and other extreme effects the content of histamine in the tissues of the organism is considerably increased [54, 126]. During painful stimulation histamine participates in accomplishing reflex reactions; histamine in the nerves during processes of excitation intensifies the synthesis and secretion of acetylcholine. The interactions of histamine with adrenaline are very complex; there are indications of the parallelism in their content. Physiological adrenalinemia can cause a compensational increase of histamine in the blood. There is also the most intimate interconnection between biogenous amines and corticosteroids [232].

Under the influence of accelerations we observed in rats not only expressed disturbances of the relationships between acetylcholine and adrenaline in the blood, but also changes of the content of such substances in certain tissues [253]. Thus, during positive radial accelerations the content of histamine considerably decreases in the lungs (4.28 μg/g in the normal and 3.3 μg/g after the effect) and cerebral tissue (from 3.94 to 2.3 μg/g) and increases in the mucous membrane of the intestines. Along with this in the investigated tissues the activity of the enzyme diamine oxidose and the content of adrenaline-like substances increased, especially in the lungs and cerebral tissue. These data indicate that accelerations cause essential shifts in the internal environment of the organism, reflecting changes in the state of the nervous and neuroendocrine mechanisms of the vegetative regulation of function. However, these shifts bear an adaptive character, about which it is possible to judge both according to the redistribution of histamine in the tissues, and also in terms of the formed relationships between the histamine level and the state of its inactivating enzymes; their effectiveness is strengthened during the progressive formation and liberation of histamine.

Under the influence of accelerations causing considerable changes in various functional systems of the organism, there are disturbances in mechanisms regulating the constancy of the internal environment, in particular the inactivating histamines, in connection with which the accumulation of free histamine in the tissues becomes possible.

Inasmuch as during the one-time-acting effects of various (in value and direction) accelerations the changes of the content of adrenaline, noradrenaline, acetylcholine, and serotonin in the blood have identical directivity, it is possible to assume their conditionality to sudden and rapid disturbance of hemodynamics as a whole. Consequently, changes in the content of these humoral factors of regulation are, apparently, not so much a result of the disturbances of the blood supply of the tissues, as of reactions to the regulation of overall vascular tonus. In the dynamics of the changes of the content of acetylcholine in the blood finds its reflection and phenomena connected with the increase of muscular activity. The latter agrees with the data of other authors studying the biocurrents of muscles during accelerations [97]. At the same time the data characterizing the changes of the activity of diamine oxidase and the contents of histamine and adrenaline-like substances in the mucous membrane of the intestines, tissues of the lung and brain, made it possible to assume that accelerations affect the course of metabolic process in the tissues themselves; the greatest changes here were detected in the tissues of brain – in all variants of the experiments the content of histamine decreased by 50%.

To the new level of homeostatic reactions during acceleration testify also the shifts in the metabolism of fats. Thus, in the research undertaken by us in this direction for clarification of the role of the small intestine in the regulation of the level of cholesterol in the blood [162] there was revealed a considerable increase of its content even as a result of a single rotation of dogs on the centrifuge (8g – 3 minute, spine-chest). In all cases the concentration of cholesterol in the blood increased from 10 to 70 mg% during the simultaneous lowering of its concentration in the intestinal juice by 5-20 mg/%. In the statistical treatment of the data the change of the direct correlation of the content of cholesterol in the intestinal juice and in the blood before the effect on the inverse correlation after it was revealed. In these experiments there was also shown the value of the functional state of the glands of the small intestine in development hypercholesterinemia. In those animals, in which the content of cholesterol in the intestinal juice after the effect of accelerations increased, hypercholesterinemia was not observed. The duration of the changes in cholesterol metabolism after a single effect of accelerations was approximately 2 months and can also have a connection, as was shown above, with the functional and structural disturbances, also appearing in the liver.

As it is known, hypercholesterinemia in dogs is difficult to cause even with the daily addition of pure cholesterol to their food. This can be accomplished only by suppressing the function of the thyroid by the application methylthiouracil [268].

Hence the assumption is logical that during accelerations disturbances also take place in the thyrohormond line of the common mechanism of neuroendocrine regulation.

The results of the conducted experimental investigation, as it seems to us, can promote an understanding of the mechanisms of increasing the level of cholesterol in the blood in flying personnel after flights on new types of aircraft [112, 121]. The data obtained by us during the examination of Soviet astronauts accomplishing first and second group flights is of special interest, - an increase of the content of cholesterol in the blood was observed in them for 2 weeks after their return from orbital flights to earth [57, 70].

Disturbances of the relative constancy of the internal environment of the organism, characterized by a prolonged aftereffect, can predetermine the overall resistance of the organism, its reactivity to living under conditions of weightlessness.

The given data on structural-functional disturbances, obtained both in experiments on animals, and also in investigations on people, testify to the great compensator possibilities of the organisms of the higher animals and man.

So expressed are the changes in the structure of the tissues of various systems, as well as the shifts in the internal environment of the organism, they are usually revealed only with the help of special methods of investigation. These disturbances are hidden and occur during a satisfactory and even good state of the organism, in the absence of essential deviations in behavioral reactions and rapid restoration of shifts in the vitally important systems of the organism (in the central nervous system, cardiovascular and respiratory systems).

The use of the neuroglandular apparatus of the digestive system as an indicator of the reaction of the organism during extreme effects of factors of space flight aids the analysis of the mechanisms of homeostasis of the organism to different levels of regulation. Along with the higher mechanisms of cortical and subcortical levels of regulation there is revealed the important role of the adaptive system of automatic control and self-regulation with variable structure. With the correct theoretical approach it is possible to foresee the course of the physiological processes and to control them for supporting the homeostatic functions of the organism, and thereby its efficiency and health.

CHAPTER VI

CONCERNING VESTIBULO-VEGETATIVE DISORDERS DURING THE EFFECT OF ACCELERATIONS AND WEIGHTLESSNESS

After the orbital flight of G. S. Titov a study of the vestibular system of man for its significance in cosmosailing occupied one of the leading places in space physiology. The vegetative disturbances, which were observed in the astronaut, were not a surprise to the physiologists. The possibility their appearance under the conditions of weightlessness was anticipated in G. S. Titov's program of training; considerable time was allotted to the training of the different physiologic systems. Tests were repeatedly performed in the flight for investigating the vestibulo-postural reflexes. At the beginning of flight G. S. Titov did not detect any difficulties in performing these tests, but noted that sharp turning of his head to the right and to the left causes an "unpleasant sensation" and dizziness. From the 4th rotation there appeared a sense of weight in the head and pressure in the region of superciliary arcs, and also unpleasant sensations in the eyeballs during movement. The performance of a test with turning of the head with arms extended forward caused a sensation of the "floating" surrounding objects and dizziness. After sleep the astronaut felt better, but as before noticed that sharp turnings of the head cause analogous sensations. A comprehensive examination after landing did not reveal functional deviations in the vestibular apparatus. However, the majority of specialists was inclined to treat the disorders in flight as vestibulo-vegetative [34, 77, 116, 271, 273].

At the present time there is too little objective data for making a judgement about the mechanisms of these phenomena observed in G. S. Titov and certain other astronauts.

At the same time a number of experimental investigations give the bases for formulating working hypotneses. Definite interest is presented by those of them, in which the gravireceptor function of the vestibular analyzer was studied.

Certain Mechanisms of the Vestibulo-Vegetative Disturbances

The most typical for the conditions of the external environment, the analysis of which is carried out by the human nervous system, is the synthetic character of the actual stimuli, their spatial and temporal stereotypy. This was clearly shown in his time by I. P. Pavlov and his pupils, studying the synthetic conditioned reflexes and the phenomena of dynamic stereotype.

Any stimulation from the external world affecting the organism, each time falls on the soil, prepared by the whole totality of preceding stimulations: "Each new agent in the central nervous system enters with it into a struggle with the agent already acting there..." [174].

Response reactions of the organism in this case are the peculiar result of the "competing" influence of the stimuli.

For the phenomena of a similar kind, revealed during the analysis of human sensations, L. A. Orbeli proposed a special term the "interaction of the afferent systems." In his opinion, the principle of the interaction analyzers is dominant in the activity of the central nervous system. From this time there began the thorough study of the problems of the interaction of different afferent systems and analyzers, concerning which numerous works testify [104, 124, 141, 142, 159, 170, 171, 194, 262, 263, 264].

With the beginning of the mastery of the Cosmos physiologists expressed assumptions that during prolonged flights in astronauts there is possible the most serious reorganization of the system of analyzers formed as a result of individual vital experience.

A similar assumption came about from the analysis of the vital activity of an astronaut in an unusual (for terrestrial existence) environment. The peculiarities of the living environment, in which man finds himself in accomplishing space flight, are the limitations of customary (for ground conditions) information (chiefly visual and motor) and the inclusion of additional stimuli, among which there belong light contrasts, various forms of solar radiation, etc.

A complex of these factors exerts an influence of the numerous specialized afferent systems. Thus, on ensemble of excitation is created against the background of the not yet studied null gravity state.

In certain astronauts illusory sensations of spatial attitude arose chiefly during the transition from the propelled section of flight to weightlessness. The astronauts B. B. Yegorov and K. P. Feoktistov recorded illusions of inverted position of the body during the null-gravity state, especially when attention was fixed on them. The false sensations were inhibited during the performance of any responsible work during the course of the experiment. Analogous illusory sensations also frequently appear in pilots during instrument flying and in adverse weather conditions. Approximately in 14% of the cases they lead to flight accidents and catastrophes [285, 364].

Attempts to clarify the causes and mechanisms of the illusions have been made by many authors [78, 79, 198, 199, 285, 297, 323, 325, 327, 331, 364]. A Graybiel, B. Clark and others [314, 323, 325, 331, 333, 335] managed to reproduce certain illusions in an experiment. They were designated oculogyral and oculogravic. The first arose during stimulation of the receptor apparatus of the vestibular analyzer by angular accelerations and appeared in the apparent movement of an object in the field of sight or movement of the field of sight itself. Oculogyral illusions can be connected with the function of the semicircular canals. In persons, when their activity was disturbed, false sensations did not appear, although the otoliths reacted normally. Besides it was established that man is very sensitive to similar illusions: distinct reaction appears during an acceleration of 0.12 m/s^2 and an exposure of 20 seconds. The authors connected their genesis with the visual track during the slow phase of nystagmus and the efferent activity of the extraocular muscles in the absence or suppression of nystagmus. Astronaut Glenn used a similar illusion in his space flight as an index of the activity of the vestibular apparatus.

Graybiel and others [326, 328, 329, 330, 331, 371] used the appearance of illusions for appraisal of the degree of orientation of subjects during multi-day rotations under ground conditions and flights on aircraft along the Kepler parabola, during which on man there act a complicated complex of several (shifted in time) overloads and short-term weightlessness. In these cases oculogravic illusions are an index of the function of the otoliths [323, 324]. Being based on the fact that the perception of fundamental motions in darkness is hampered, especially during the influence of accelerations, the authors set up appropriate experiments in a Link cabin and under actual flight conditions. They indicate that in such experiments, besides the effects from vestibular stimulations, there appeared a special form of visual illusion – the so-called autokinetic illusion, i.e., the apparent movement of an object in the field of sight.

All these experimental illusory sensations are connected with the ideas about the dominating role of the vestibular analyzer in their pathogenesis. False spatial perceptions in the experiments of Graybiel, Clark and others are reminiscent of the illusions of counterrotation and the sensations, appearing in man during the action of Coriolis accelerations. In all cases the vestibular apparatus was subjected to stimulations, exceeding to a considerable extent the threshold values. In our opinion, certain illusory sensations in pilots during flights with different evolutions of aircraft, and also in astronauts under the conditions of transition from "overloads" to weightlessness are close (according to mechanism) to those described. Meanwhile, spatial disturbances in flying practice cannot in all cases always be connected with excessive superthreshold stimulations of the vestibular or any other analyzer. In certain cases adequate vestibular stimulations turn out to be subliminal. Thus, for example, false sensations of body position can appear for pilots in horizontal flight (in clouds, in adverse weather conditions) or in performing turns, where the angular velocity is less than 1°/s. B. Giffen [314] describes the special sensation of "hanging" in the air in pilots during instrument flying at uniform speed at high altitudes (20,000 feet), accompanied by fear and vegetative crises. Analogous phenomena were observed by him during the submersion of a man in water and when the subject was for a long time in bed, being deprived by nontransparent glasses of the possibility to orient himself to the surrounding situation. In the latter case hallucinations frequently appeared.

Regarding illusions in weightlessness, then, according to astronaut B. B. Yegorov, there are not sufficiently convincing arguments to consider the vestibular apparatus guilty of their origin. Similar observations confronted the investigations with the necessity to look for explanations, not connected with the activity of any one analyzer system. There appeared the idea of the physiological systemicity of analyzors, providing spatial orientation [114, 115, 116, 237].

With a prolonged state of weightlessness there is connected the appearance of vegetative reactions, reminiscent of the symptom complex of motion sickness, which provided the grounds to formulate a conclusion about "satellite sickness" [116]. However, confronting the researchers there were then and there serious difficulties. First of all the etiology and pathogenesis of motion sickness cannot be placed in the framework of a single system. Various points of view as to the basic cause of these phenomena:

1) motion sickness – the result of prolonged stimulation of the otolithic apparatus during vertical various-directed shifts of a man [69, 78, 128, 129, 258, 260, 336];

2) a similar state can develop during the stimulation of the cupoloendolymphatic system (the so-called sickness of the canals) [167, 170, 344, 345];

3) vegative disorders – the result of the disturbance of the interaction of the otolithic and cupoloendolymphatic systems [383];

4) the vegetative syndrome during "motion sickness" – the result of the displacement of the internal organs and stimulation of the numerous interoreceptor and vegetative centers [115, 116, 229, 246, 248], possibly of the diencephalic region and the reticular formation;

5) an analogous effect is possible apparently, during the stimulation of the proprioreceptors [115, 116, 202, 208];

6) these describe the conditioned reflex mechanisms of "motion sickness" [50, 119, 185, 202, 208];

7) disturbances of the physiological interrelations in the system of analyzers of the position and displacement of the body in space.

Thus, the genesis of the so-called motion sickness is very complicated. In it there participate various systems of the brain and spinal cord, and also numerous peripheral apparatuses.

An astronaut, moving inside a ship or performing inclinations of the head and trunk, theoretically should experience the influence of such a complex system of forces that in a number of cases it is difficult to determine the vector of the resultant. Apparently, in certain situations there can be created the conditions for the appearance of Coriolis accelerations. The latter may cause in the human organism expressed circulatory disorders. Our attempts to calculate these accelerations during the rotation of a ship in one plane and of the simultaneous movements of an astronaut led to values, which are tens of times less than the established thresholds of the sensitivity of the vestibular apparatus [332, 322, 360, 378, 379].

Theoretically it is possible to assume the possibility of the cumulative influence on the astronaut of Coriolis accelerations [260], but, considering their small value, a similar assumption becomes reality only in that case, when the thresholds of the sensitivity of the vestibular apparatus are essentially changed. Otherwise the stimuli turn out to be beyond the limits of their perception.

The attempts to comprehensively investigate the vestibular function in man and animals in flights on aircraft along the Kepler parabola encounter serious methodical difficulties. First, the period of zero gravity, as the exact measurements of M. M. Jackson (340) showed, could be made to last only up to 10 s. Secondly, weightlessness is precedent by accelerations, which, undoubtedly, leave some trace reaction [246]. How important it is to consider this circumstance, are shown by the following data. The bioelectrical activity of the sacrospinal muscles was investigated during the stimulation of the vestibular apparatus by a pulsed current. The period of the aftereffect of the stimulus, close in its value to the threshold values, continued more than 1 minute. The investigations of V. A. Kislyakov [106, 107, 108], R. McLay, M. Madigan [359] and other authors [106, 108, 359] testify to the duration (tens of seconds) of the duration of the post-rotation nystagmus, where the more thoroughly is carried out the investigation, the more clearly the shift is observed in the direction of the phases of the nystagmus.

The same was detected with respect to the sensory vestibular reactions by M. D. Yeml'yanov and co-authors (illusions of pitch) [2, 88] and by O. M. Frenkel (in 80% of the cases the phase course of dizziness is after rotation) [237].

Hence not accidental are those contradictory data which were obtained by Ye. M. Yuganov [273] and Jackson [340] in the investigation of the function of the vestibular apparatus in man under conditions of flight along a Kepler trajectory. The former ascertained the lengthening of the post-rotation nystagmus, the latter, using a stronger stimulus (Coriolis acceleration), - the very exact method of recording accelerations and photonystarmography in infrared light, did not detect changes of the reactions of nystagmus. The opposite results were also obtained by other authors [338, 284, 376].

Ye. M. Yuganov, I. I. Kas'yan and A. I. Gorshkov [270, 272, 274, 275] consider that to draw a conclusion about the lowering of the functional activity of the vestibular apparatus in weightlessness it is too early. The influence of weightlessness, in their opinion, does not lead to the functional turning off of the otolithic apparatus, which in this case serves as the source of unusual, increased afferentation. As a result of the accumulation of similar stimulations there appear symptoms of "spatial motion sickness." The activiation of the otoliths leads, in particular, to reduction of the duration of post-rotational nystagmus and to the illusion of counterrotation.

In the light of these data the recent works of W. Johnson, R. Money, A Graybiel [347], conducted on apes are not without interest. The animals - healthy and with either removed semicircular canals, or removed otoliths - were subjected to the action of short-time weightlessness; they considered the complex of physiological, chiefly vestibulo-vegetative reactions. The authors came to the conclusion that weightlessness by itself cannot cause motion sickness; the latter has its origin in angular accelerations acting in different directions. Apparently, the results of investigations on aircraft cannot be used in their totality for appraisal of the state of the organism under conditions of prolonged weightlessness.

Summarizing the presented considerations, it is necessary to recognize, that the role of the vestibular apparatus under conditions of weightlessness remains in many respects unclear.

The State of Certain Analyzers Under the Conditions of Space Flight

Certain astronauts experienced difficulty in estimating distances to objects in an unoriented field. For example, McDivitt in the flight on "Gemini-4" during an attempt to meet with a second stage carrier rocket consistently estimated the distance from the ship to the rocket by approximately 5 times less than it was in reality. Along with this Cooper during his flight on the "Mercury" ship distinguished from orbit trains, roads, rivers, and from a height of 163 km – houses on the Tibetan plaueau. The astronauts piloting "Gemini-10" were supposedly able to see on earth motor vehicles and groups of people. Similar reports served as a basis to draw a conclusion about the unexpectedly high characteristics of human vision in space [365].

On the whole the conclusion of the American colleagues on the "Gemini" ships was that the visual function in space flight is stable and there are no bases to ascribe to weightlessness a negative influence on the visual analyzer. The poor visibility of ground landmarks, in their opinion, was caused by atmospheric contaminations. At the same time attention is focused on the essential difference of the thresholds of the viewing angle under ground conditions and in distinguishing objects from a spaceship.

Soviet astronauts focused attention on the negative influence of optokinetic stimulations in tracking through the portholes the smallest extra-cabin objects. Prolonged observations caused unpleasant sensations, similar to the initial motion sickness syndrome.

Under conditions of short-term weightlessness there is observed a comparatively rapid adaptation of the motor analyzer and the restoration of motor coordination. In orbital flights with a duration up to 8 days and in existing from the spaceship (A. Leonov) astronauts did not experience noticeable difficulties in motor acts. The assumptions about the decrease of proprioceptive afferentation are not devoid of bases, but they also have not been confirmed experimentally. The attempt of Margaria [356] to extrapolate by mathematical methods data on the movement of man on earth in reference to the conditions of lowered gravitation made it possible for him to draw the conclusion that man on the surface of the moon will be able to move only by running.

I. T. Akulinichev, M. D. Yeml'yanov and D. G. Maksimov [2] investigated in astronauts in flight the motor activity of the eyes with the help of electrooculograms. The eyeball and its transversotriated musculature is a good model for studying the processes of establishing motor reflexes in weightlessness, and also can serve as a source of information for appraisal of the vestibular function.

The analysis of the electrooculograms for A. G. Nikolayev, P. R. Popovich and V. F. Bykovskiy showed that during the 3-5 day stay in the null-gravity state stable disturbances of the motor coordination of the eyes (Fig. 27) were absent. This confirms that

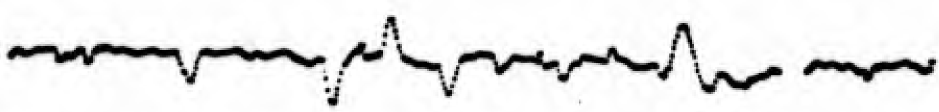


Fig. 27a. Sample of an electrooculogram of an astronaut in orbital flight.

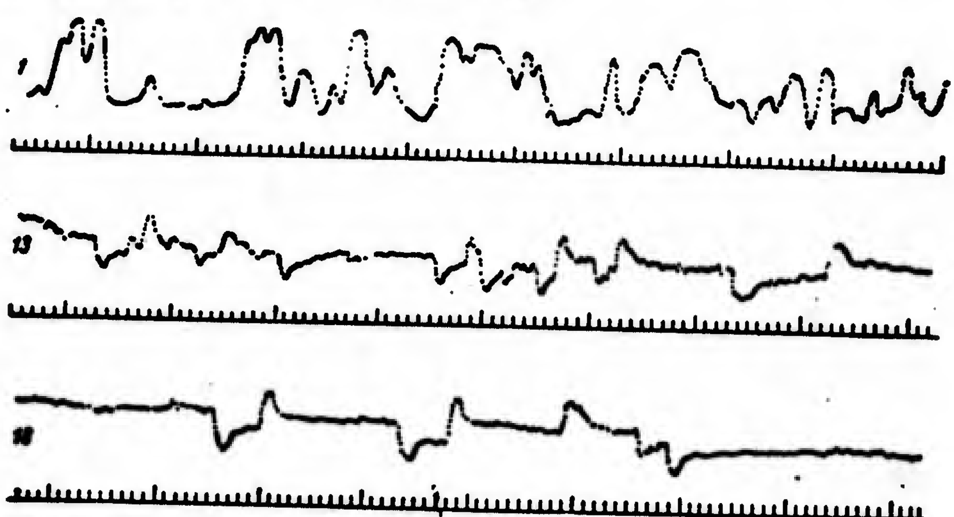


Fig. 27b. Electrooculogram of V. F. Bykovskiy. The figures on the left — the orbits around the earth.

the adaptation of the motor analyzer occurs rather actively. However, for deep understanding of the mechanism of this process there are needed more perfected methods of recording the motor activity of the eyes during space flight.

In certain American reports [340] it is emphasized that there were no vestibular disorders in any of the astronauts during orbital flight. Hence the problem of "satellite sickness" for American researchers is not deserving of attention. This is somehow confirmed by researchers on "Gemini-5", where Conrad with help of special device with mobile light been determined in a state of weightlessness the position of the subjective horizontal which turned out rather accurately for him.

The selection and training of Soviet astronauts are based on the differentiational approach to specialists of different professions, who all the more frequently will be attracted to research work in flight on spaceships and orbital stations. Hence a certain lowering of the requirements for the rating of the vestibular function is possible.

The subjective sensations of astronauts, in which there were observed vegetative disturbances in flights, were no supported to a sufficient degree by the results of objective investigations of the vestibular function. The latter did not make it possible to detect disturbances of the excitability of the vestibular analyzer (according to sensory and motor reactions).

During certain orbits in V. V. Tereshkova there were detected eye movements, similar to nystagmus during vestibular investigations on earth (Fig. 28). However, these movements did not justify talking about the appearance of vestibular disorders.

B. B. Yegorov showed that the thresholds of excitability of the vestibular apparatus to electrostimulation under conditions of weightlessness with a duration up to 24 hours do not change. It is true, the investigations did not have a dynamic character and tests were not conducted on the reactivity of the vestibular apparatus to increasing (in intensity) electrical stimuli. Vegetative reactions

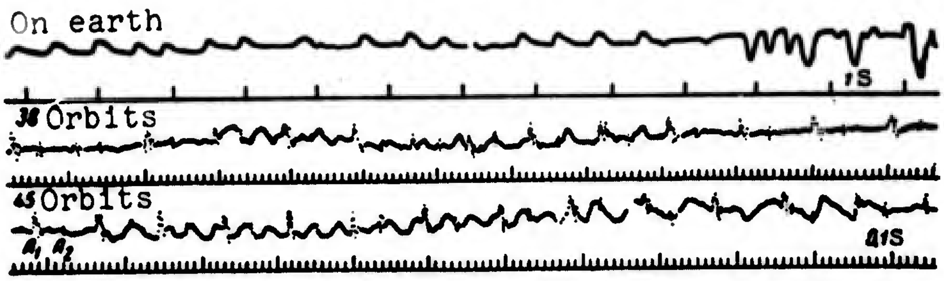


Fig. 28. Recordings of post-orbital nystagmus in V. V. Tereshkova in the pre-launch period and nystagmus movements of the eyes during orbital flight.

of the motion sickness type in all three astronauts of the "Voskhod-1" ship were absent. The origin of the illusory sensations of inverted position, which took place in B. B. Yegorov and K. P. Feoktistov almost during the whole extent of the null-gravity state, is unclear. Optokinetic stimulations (observations through the portholes) intensified the unpleasant sensations. Inhibition of the illusions was carried out with help of muscular tensions and active cortical activity (performance of the flight assignment).

New materials for treatment of the above described phenomena connected with the so-called motion sickness syndrome, in particular, observed under conditions of weightlessness, were obtained as a result of special experimental investigations. There is no doubt that the pathogenesis of the illusory sensations and disorders reminiscent of the motion sickness syndrome in space flight should be examined with respect to disturbances of the cortical and subcortical levels of regulation of functions connected, in particular, with changes of the regularities of interaction and coordination of the visual, vestibular and motor analyzer.

In literature it has not been possible to find information reflecting the significance of the interaction of analyzers in the reactivity of the vestibular apparatus. But there are works, where the influence of the vestibular and motor analyzers on the state of visual functions was studied. The change of visual acuity and the light sensitivity of the eyes under the influence of vestibular stimulations or active muscular activity [104, 124, 159] was shown.

V. G. Samsonova [214], G. I. Gorgiladze and G. D. Smirnov [80] by a delicate electrophysiological method showed the influence of vestibular stimulations on the activity of the neurons of the visual region of cerebral cortex. V. G. Samsonova considers that the detected inhibition of the bioelectric activity is the physiological basis of the essential shifts of the visual functions appearing during vestibular stimulations under extreme conditions which can entail distortion of perception and optical illusions.

An important result of the investigations of V. S. Nazarenko [163] is the fact that he could discern the principles of the inhibition of the vestibular (namely, the vegetative ones) reactions by combined stimulations of certain analyzers (olfactory, auditory, visual). The author showed that among the ensemble of stimulations it is possible to find optimum combinations from the point of view of effect on the function of the vestibular analyzer. This investigation belongs to the region of the purposeful effect on the vestibular analyzer with the possibility of regulating of its functions by means of specific adjustment of the system of analyzers as a whole.

V. S. Nazarenko also detected another important fact: the type of vegetative reaction inherent to each stimulus individually, is preserved, if the stimuli are combined. Together with that the physiological effect of the action of a complex combined stimulus is not the sum of the action of the components, but constitutes a single system, in which each of the components loses its own independent value. The point of view is confirmed, according to which the symptom complex of motion sickness can be practically obtained during stimulation of any sensory organ.

Among the numerous reflex reactions expressing definite relationships between the afferent systems, V. N. Chernigovskiy [263] distinguishes the "inherent" reflexes as mechanisms directed towards the regulation of the physiological system, with which functionally and phylogenetically the given receptive field is connected. The "inherent" reflexes are characterized by lower thresholds and slow adaptation; at its basis lie not so much the changes of excitability of the receptors themselves, as the development of inhibition in the corresponding centers.

We had the right to assume that precisely according to this principle there must be realized reflexes inside the system of analyzers, providing spatial analysis.

To the investigations revealing the overall principles of the interactions of the afferent systems belong the work of V. V. Frol'kis [238], who subjected the various receptor fields to overall stimulation (the upper sections of the respiratory tracts, the region of the carotid sinus, the mucous membrane of the rectum, the urinary bladder, and others).

The final reflex effect the author explains by the phenomena of the summation of stimulations, which are carried out at different levels of the nervous system. The summary effect appears not only during intense stimulations and influences of average severity, but what is especially important, also during subliminal stimulations of the receptors. For example, simultaneous subliminal stimulation of the mucous membrane of the urinary bladder and the rectum caused a rise of blood pressure by 20-30 mm Hg, whereas each stimulus individually did not lead to the indicated effect.

In reference to the analyzers it is necessary to additionally consider the phasicity of their activities. The response reactions in many respects will depend on which phase one another stimulus [124] falls in.

Investigations were conducted on specially designed laboratory equipment: a rocking chair (Fig. 29), a rotating chair on a shifting support (Fig. 30), a revolving (around the subject) cylinder with black and white strips drawn on the internal surface, a slowly revolving room. The speed of the rotations of these devices was regulated within the ranges of from 0 to 360°/s.

On Fig. 30 there is depicted a chair, in the seat of which are placed strain gauges for recording the variations of the center of gravity from the vertical to the right – to the left, forward – backwards. The recordings of the movements of the torso with the help of

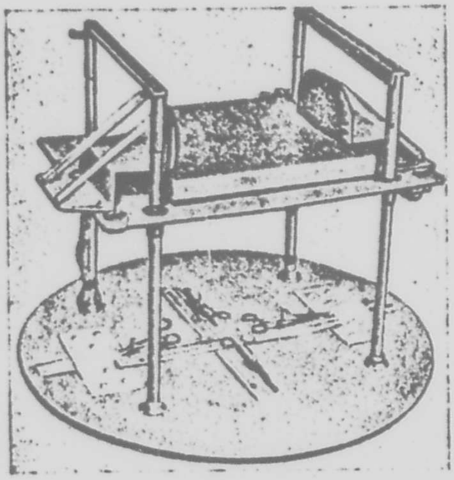


Fig. 29. The rocking chair

Fig. 30. The rotating chair on a shifting support.

stress gauges built-into the chair, made it possible to investigate the qualitative and quantitative characteristics of the vestibulo-spinal reflexes. In this case there was used the principle of stabilography proposed by V. S. Gurfinkel, Ya. M. Kots, and M. L. Shik [82], for the characteristic of motor reflexes connected with the stimulation of the vestibular apparatus. Difference consisted in the fact that in experiments of M. D. Yeml'yanov with his colleagues teh subject was in a sitting position and numerous investigations were required for estimating the tensometric curves at a different degree of stability and stimulation of the vestibular apparatus with increasing (in intensity) stimuli. To sum up a comparative appraisal was given of the obtained tensometric curves with those curves, which reflected the oscillations of the center of gravity of the subject in a state of balancing without additional vestibular stimulations. The number of large oscillations per minute, the average amplitude of the oscillations and the amplitude of the maximum deviations of the overall center of gravity were calculated.

Besides the adequate stimuli of the vestibular apparatus (angular acceleration and Coriolis acceleration), there was also used a pulsed current with a square characteristic of pulses.

By electrical stimulation, as is known, it is possible to cause reflexes analogous to those, which appear during adequate stimulations of the vestibular apparatus or the so-called calorific test [157, 164-167, 227, 256, 289, 290, 355, 357]. A very important circumstance in the use of electrical current is the possibility of exact apportioning of the stimulations (from the subliminal and higher) in a wide range. Moreover, the pulser can be so portable that it is possible to carry out investigation during space flights.

For excitation of the visual analyzer there were used the following stimuli: a white light of varied intensity, immovable and movable visual objects in an unoriented field, and panoramic motion pictures with pictures of various evolutions of aircraft. The unoriented field was created by a special flap-vessel filled with latex (a suspension of synthetic rubber in water) attached to the head in front of the eyes of the subject.

For excitation of the motor analyzer there were used two essentially different stimuli, changing the character of proprioceptive afferentation, - static muscular stresses of the skeletal muscles and the shifting support (the rocking chair).

In counterbalance to the static muscular tensions during shifting equilibrium according to the decrease of the area of support in the beginning there appears a rhythmic reflex with a relatively regular alternating of the deflections of the center of gravity from the vertical, constituting a compensator reaction for retention of a definite body position in space. Subsequently the compensator mechanisms are disturbed, which has an effect on the character of the tensometric curves and on the muscle myogram used in the experiments - the straightened spine: the myographic effects to the right and to the left, at first corresponding to the deflections of the center of gravity from the vertical, become disorderly and do not fit into the framework of any kind of principles. We consider that the shifting equilibrium of man on earth is not nearly an analog of weightlessness, but, apparently, judging from the myograms, both these states considerably change the character of proprioceptive afferentation. Furthermore, it was ascertained that with an increase of the degree of instability the electroencephalogram is changed. Oppression of the alpha rhythm is observed; the appearance of the beta rhythm and peak-like oscillations (Fig. 31), which, apparently, is caused by a decrease

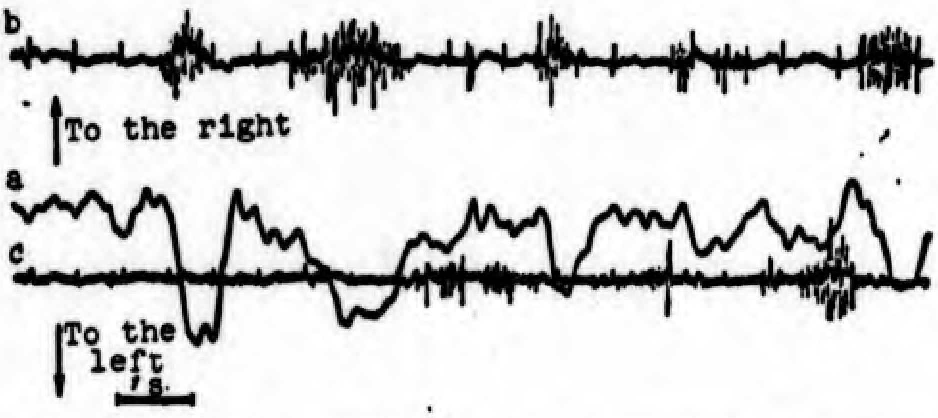


Fig. 31. Stabilogram and electromyogram (EMG) of the sacrospinal muscles in subject B, in the period of balancing on the shifting support. a - stabilogram; b - EMG to the right; c - EMG to the left. Designation: EMG = ЭМГ.

of the activity of the inhibitory processes in the cerebral cortex and in turn facilitates the irradiation of excitation from the vestibular centers to the motor zone of the cortex and vegetative centers.

Experiments were carried out with a different combination of stimuli for the vestibular, visual and motor analyzers; their quantitative characteristics were considered.

The objective indices of the activity of one or another analyzer were chosen: a) sensory reactions (illusory sensations and a change of the character of a consistent visual Purkinje image); b) motor reflexes (vertical writing, oculogram, biopotentials of the muscles of the neck and spine); c) vegetative reactions (pulse rate, respiratory rate, arterial pressure, bioelectric activity of the heart); d) biopotentials of the brain (temporal and occipital tappings).

Investigations carried out on a man showed that the vestibular analyzer can be brought into an active state by stimulations, which lie beyond the limits of sensations and thresholds, determined by universally recognized methods (by illusions or nystagmus). This activity finds reflection in the amplification of the biopotentials of the skeletal muscles on the part of the stimulated labyrinth (Fig. 32). At the same time the bioelectric activity of the muscles depends on functional state of the visual analyzer. Visual stimulations

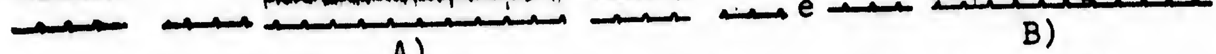


Fig. 32. Bioelectric activity of the neck and sacrospinal muscles in subject V. after stimulation of the vestibular apparatus to the left by a pulsed current of subliminal force (1 mA). A) the eyes are closed; B) fixing the glance on a shining lamp of 2.5 V; a, b) EMG of the neck and sacrospinal muscles to the right; c, d) EMG to the left; e) time 1 second.

associated with fixing of the glance on an immovable object, inhibit the described reaction (Fig. 33). In the absence of an inhibitory reaction there are created the conditions for the accumulation of weak, imperceptible stimulations in the vestibular centers, which noticeably intensifies the described bioelectric effect and extends it in the period of the aftereffect of the vestibular stimulations.

Thus, it is possible to obtain an accumulation of vestibular stimulations, which lie beyond the limits of thresholds, determined by sensory reactions to nystagmus, without essential changes of the functional state of the vestibular analyzer.

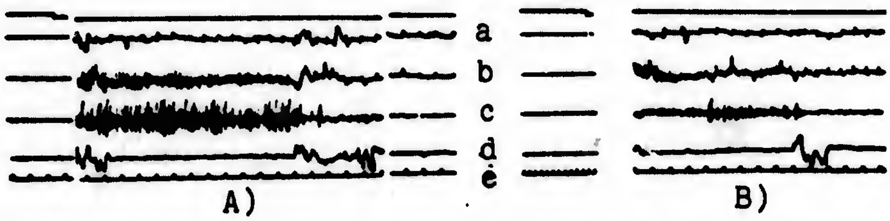


Fig. 33. Bioelectric activity of the neck and sacrospinal muscles for subject B. A) the eyes are closed; B) fixing of the glance on a lamp; a, b) EMG to the left; c, d) EMG to the right; e) time 1 second.

In the absence of visual control of body position in space the static muscular stresses of the neck, inclinations of the torso, and also muscular stresses obtained by manual (and especially backbone) dynamometry, considerably inhibit the vestibulo-sensory and somatic reflexes (neck and on muscles - extensors of the spine). There most distinctly appears inhibition during tension of muscles on the side opposite the stimulated labyrinth (Fig. 34). Simultaneously vestibular chronoximetry conducted under conditions of such inhibition shows a lowering of the thresholds of vestibular sensitivity, and during use of adequate stimulations of the vestibular system (angular accelerations) there occurs a decrease of the duration of the illusion of counterrevolution on the average by 8 seconds. Conversely, during shifting equilibrium there is observed an amplification of all forms of vestibular reactions and the more expressed the less the area of support for the subject, i.e., degree of stability (Fig. 35).

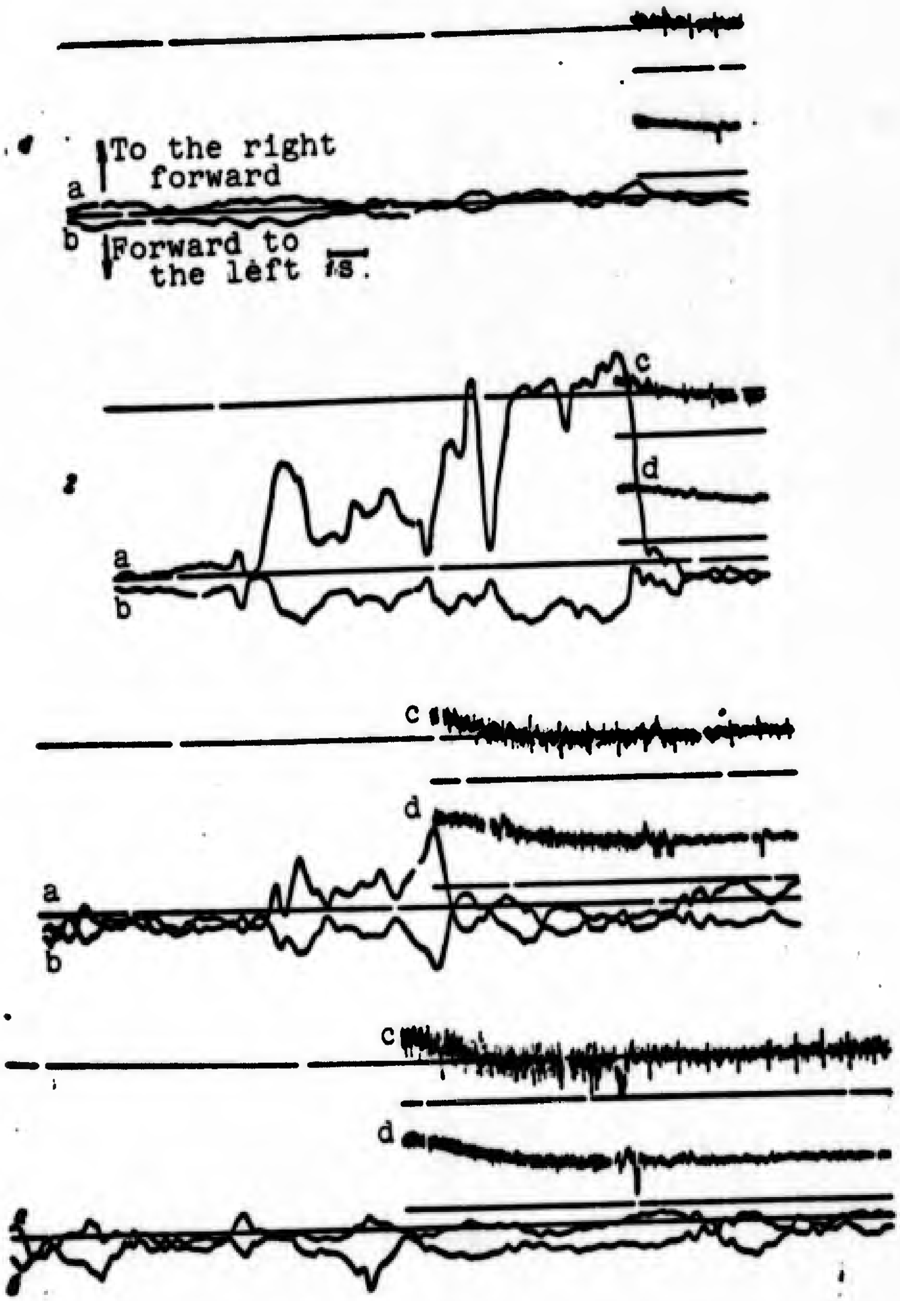


Fig. 34. Stabilogram of subject G. during stimulations of the vestibular apparatus from the right with pulsed current of threshold strength. 1 – control; 2 – irritation without inclinations of the head; 3 – the same with inclination of the head to the right; 4 – with inclinations to the left; a) movement of the torso to the right – to the left; b) forward – backward; c) EMG of the neck muscles from the left; d) from the right. Interruption in the vertical lines – the period of stimulation. Straight lines – nonoperating loops of the oscillograph.

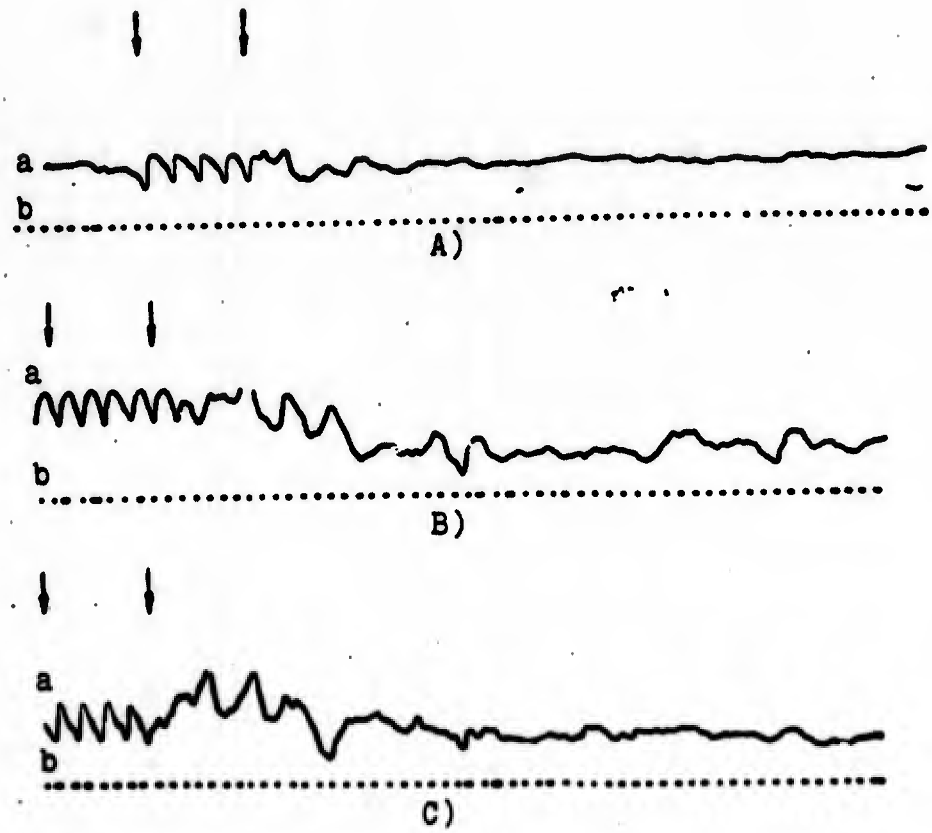


Fig. 35. Curves of the recording of trunk movement for subject Z. after five rotations on a Bárány chair. Shifting support. A) area of the support 625 cm^2; B, C) area of support 289 cm^2; a) movement to the right – to the left; b) forward – backward; c) time 0.5 of a second. First arrow – the beginning, second – the end of rotation.

Experiments showed that 5-fold revolution with a speed of 1 turn in 2 seconds and the subsequent stopping does not cause motor reactions, if the subject rather distinctly senses the direction of terrestrial gravity (during shifting on an unstable support with a rather large area – 600-800 cm^2). In subjects resistant to vestibular stimulations there does not appear here illusions of counterrotation. But when the area of support is reduced almost by half (to 289 cm^2) and the deflections of the center of gravity from the vertical during balancing are sharply increased, the influence of the 5-fold rotation with the subsequent stopping of the chair causes in the subject complete disorientation in space, accompanied by vegetative disorders (paling of the face, quickening of the pulse, intensive perspiration, nausea).

During balancing in man the thresholds of vestibular sensitivity (depending upon the degree of instability) decrease by 2-3 times, which distinctly appears during investigation of vestibular chronaximetry – regular and iterative – with the help of a pulsed current (Fig. 36).

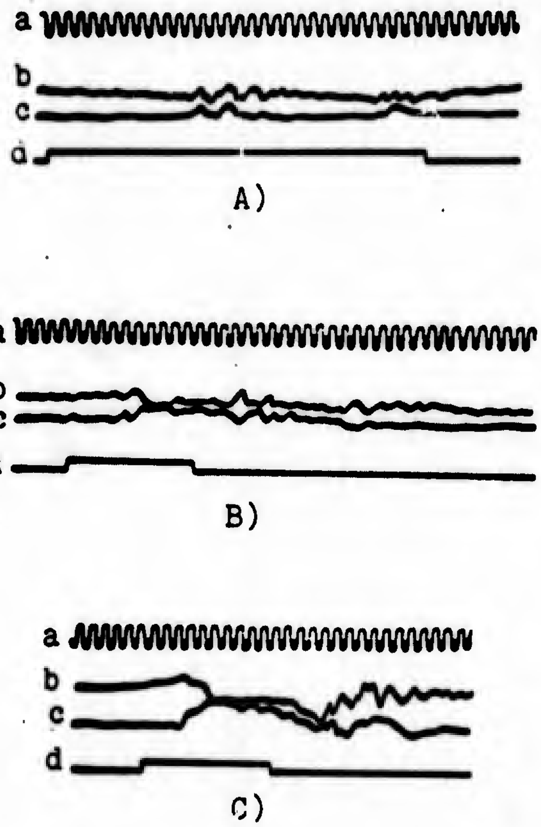


Fig. 36. Stabilogram of subject I during balancing on an unstable support. The eyes are closed. A) control, the area of support 900 cm^2; B) stimulation of the right vestibular apparatus by a current of 2 mA; C) stimulation by a current of 0.8 mA, the area of support 625 cm^2. The active motor reaction at the time of stimulation and in the period of the aftereffect; a) time 0.5 of a second; b) movement to the right – to the left; c) movement forward – backward; d) indication of stimulation.

From Fig. 36 it is clear that the motor activity of the subject at the time of stimulation of the vestibular apparatus and in the period of the aftereffect, which is an expression of the vestibulo-spinal reflexes, increased in proportion to the reduction of the area of support, in spite of the lesser strength of the pulsed current (0.8 mA). The deflection of the tensometeric curve (B) from the horizontal line exceeds 5 mm, whereas normally it is not more than 2 mm.

The investigations of Marinesckos and Kreindler [357], N. V. Timofeyev [227] and A. G. Krivosheina [125] showed that reactions of the vestibular analyzer, caused by the influence of the pulsed current, are the result of the summation of stimulation.

Numerous variants of the frequency characteristics of the current, which were used by us [88] for the purpose of studing the mechanisms of its influence on the vestibular function of man, showed that square pulses with a force of from 0.5 to 3.5 mA during a frequency characteristic of 10 imp/s, a duration of 100 m/s and intervals of 0.8-0.9 seconds caused chiefly otolithic reactions. Inasmuch as the otolithic apparatuses participate in the perception of the forces of gravitation, the fact itself of the lowering of the thresholds of sensitivity during the change of character of proprioceptive afferentation has, in our opinion, essential significance both for the development of methods of investigation of the vestibular function, and also for estimating vestibular reactions in weightlessness.

Besides the phenomena of the interaction between the vestibular and motor analyzers, the effects going from the eye to the vestibular apparatus are of independent interest.

From the practice of otolaryngology it is known that the vestibular reflexes are expressed to a lesser degree with the eyes opened. It was earlier assumed that this is result of the action of light. Experiments showed that a luminous flux, causing illuminance on the pupil of up to 160 lx coming from an "unoriented" space, does not cause inhibition of the function of the vestibular apparatus (Fig. 37).

As also with closed eyes, stimulation of the vestibular receptor in combination with the indicated illumination of the eyes led to a

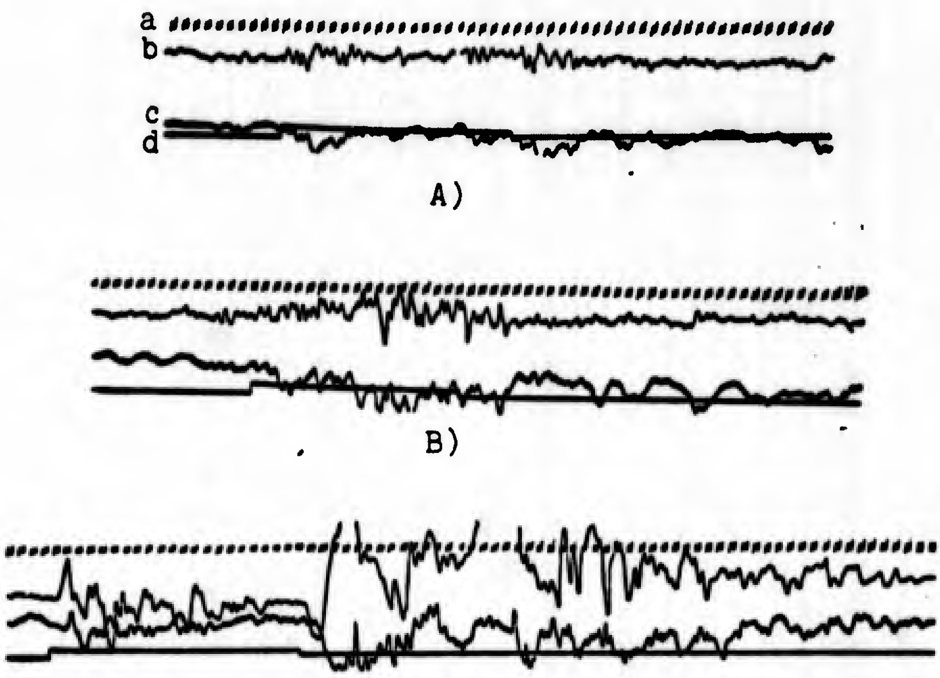
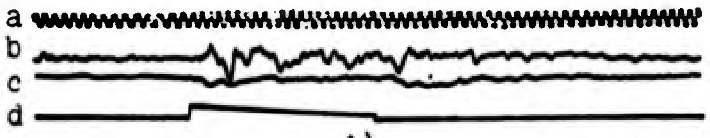


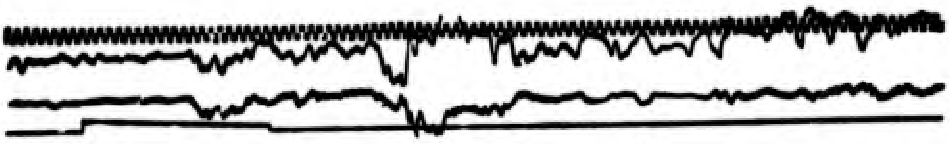
Fig. 37. Stabilogram of subject Sh. on an unstable support. A) stimulation by pulsed current of threshold force of the vestibular apparatus on the right. The glance is fixed on a lighted lamp; the illuminance on the surface of the pupil is 160 lx with the absence in the field of view of objects; a) time 0.5 of a second; b) movement to the right – to the left; c) movement forward – backward; d) indication of stimulation.

loss of equilibrium in the subject, being in a state of balancing, and a lengthening of the period of aftereffect of the stimulus. Another effect during stimulation of the vestibular analyzer can also be observed, if in the field of view of the subject there were placed customary (for him) visual objects. The fixing of the glance on fixed objects had the same effect on the vestibular apparatus, as the action static muscular stresses. Conversely, the fixing of the glance on moving objects (for example, a moving lamp) increased vestibular sensitivity.

However, not every fixing of the glance on a fixed visual object inhibited vestibular and motor reactions. The greatest inhibition was observed during the location of the visual object from the subject at a distance of 40-80 cm along the center line at the level of the eyes. The visual objects located nearer or at an angle of sight of more than 30° did not have an inhibitory action on the vestibular reactions or it was insignificant (Fig. 38).



A)



B)

Fig. 38. Stabilogram of subject M. A) the state of balanced equilibrium on a shifting support during fixation of the glance on a shining lamp of 2.5 V, located in front of the subject. Stimulation of the right vestibular apparatus with a current of 1.5 mA; B) the same, the lamp is located to the left at an angle of sight of 30° (loss of equilibrium) a) indication of time of 0.5 of a second; b) movement to the right – to the left; c) movement forward – backward; d) indication of stimulation.

Thus, inhibition of vestibular reactions by stimuli coming from the visual analyzer is caused mainly not by the peculiarities of the object, but by its position with respect to the observer and by its immobility. In the mechanisms of inhibition the basic role is played not by the light as an adequate stimulus of the visual analyzer, but by adjusting reactions of the eye with its external muscles.

It is known that external eye muscles possess a well-developed receptor apparatus. A. A. Ukhtomskiy, analyzing the function of depth (stereoscopic) vision, wrote: "The question here is the complex receptor, directed towards metric perception of forms in three dimensions and constituting a coordinated combination of simultaneous visual, musculo-proprioceptive receptions with auxiliary tactile receptions" [231]. I. M. Sechenov emphasized: "Proximity, distance, and height of objects, the paths and speeds of their movements – all of these are products of muscular sensation" [217].

The appearance of principles of the interaction of vestibular, motor and visual analyzers made it possible for M. D. Yemel'yanov with colleagues to carry out experiments on the reproduction of illusory sensations.

Attempts to connect the illusions of astronauts under conditions of weightlessness with the function of the vestibular analyzer encountered significant objections. This, apparently, is connected with the circumstance that the role of the vestibular analyzer in spatial orientation, especially in flights on contemporary aircrafts, in general, has been insufficiently studied.

On the one hand, we encounter, it would seem, the rather convincing investigations of I. S. Beritov with his colleagues [44, 45, 46, 47]. The experiments conducted by them were based on the principle of the creation in animals (dogs and cats) of conditioned reflexes in response to various vestibular stimulations. As conditioned stimulations there served the transfer to cages of animals with closed eyes at various distances and along changing trajectories, raisings and lowerings of the cages; moreover, the height and the speed of the raising were varied. I. S. Beritov revealed that in animals after several combinations reflexes will be formed for given conditions with rather exact differentiation. For example, if the animal was transferred a great distance with respect to the position of the feeder, then after getting out of the cage it returned rather soon to place of its location. If the height of the raising of the cage did not correspond to assigned (instead of 2m-4m), then the animal did not react. The change of the speed of raising from 1-2 up to 4 seconds also did not cause a reaction. With the destruction of the labyrinths similar reflexes could not be produced.

The author arrived at the conclusion that orientation in space can be accomplished under the influence of only some labyrinthine stimulations, that the cortical section of the vestibular analyzer very exactly and differentiationally reacts to stimulations of the labyrinthine receptors.

V. V. Strel'tsov, A. P. Popov [198, 199], Schöne [377] and others, on the other hand, consider that the vestibular analyzer in the spatial orientation of pilots in flights does not play a primary role. Considerable correlation of its functions is carried out with the help of the visual or motor analyzer [79]. With closed eyes a pilot cannot even fly 2 minutes [198, 199]. Gerathewohl, carried out flying experiments in determining orientation in space with sight cut off. The tests were carried out in turning 360° with banking of 45-60°, angular velocities of 6-10°/s and a radius of 150 m. The results were equivalent ot guessing [312, 313].

A. P. Popov sees the cause of the genesis of disturbances of space orientation in flight in the change of coordinational relations in the system positon analyzers and the displacement of the body in space. Creating in different variants disparities between the visual vertical (inclinations of visual objects) and the sensations of gravitation (with the help of a centrifuge), the subjects were deprived of the possibility to correctly estimate the position of their own bodies [282, 393-396]. In perceiving the vertical the afferent systems sensing the gravitational influences have greater influence than visual perceptions. The latter help orientation in space, if the eyes are fixed on fixed visual objects. Great significance in space orientation is attributed to the postural reflexes [78, 79].

We reproduced in the experiment illusions of banking (illusions of falling in a frontal plane), of inclinations forward and backward and false sensations of inverted position. These illusions were treated as cortical reactions appearing during stimulation of the vestibular analyzer and during insufficient or distorted information about the position of the body in space on the part of the visual and motor analyzers. Illusions appeared even during subliminal stimulations or stimulations close to threshold. They were the result of the summation of weak stimulations in the central sections of the vestibular analyzer during conditons, when the inhibition of vestibular reactions on the part of visual and motive analyzers had attenuated.

Illusory sensations appeared at the time of the application of stimulation and in the period of aftereffect. They were accompanied by a complex motor reaction directed towards maintaining the equilibrium of the body and at the same time not yielding to rather exact analysis. As an example there can serve the experimental illusion of banking. The course of reproducing this illusion anticipated first of all the determination of the thresholds of the sensitivity of the vestibular analyzer by iterative chronaxy. Then the subject was seated in a dark chamber in a seat with pneumatic support. For each there was selected such state of unstable equilibrium, which was rather well maintained by means of balancing for a minute. The subject looked at an illuminated square, and at the same time there was carried out stimulation of the right and left vestibular apparatus by a current of subliminal and threshold force with the gradual increase of the summational time of the influence. After each stimulation the current and the light were turned off. With a specific current intensity (from 0.5 to 1.5 mA) and time of influence (from 5 to 20 seconds) in the subject there appeared either immediately after the turning off of the stimuli, or upon the expiration of the latent time, calculated at 2-4 seconds, a distinct sensation of banking in the direction opposite to the usual motor reaction observed during stimulation of the vestibular analyzer by the electrical current. Moreover, the subject lost the ability to maintain equilibrium. He made attempts to take the initial position, but the insuperable sensation of pull in the direction of the perceptible illusion again disturbed the equilibrium. Such a "struggle" for the maintenance of equilibrium continued sometimes for 30-40 seconds. In the course of the experiment the deflection of the body was recorded on a kymograph. If the light remained in the form of a lamp, which was fixed by the glance, then the described phenomena after turning off the current did not appear and in the subject there was not observed disturbances of equilibrium (Fig. 39).

In cases of increased sensitivity — vestibular or towards unstable equilibrium — there was noted a phasicity in flow of illusory sensations: the apparent banking in one direction alternated with a false sensation in other. The described illusions were assessed as a result of the conflict situations inside the first signaling system of reality.

In the experiment another experimental illusion was also reproduced, which was treated from positions of creating conflict situations between the first and second signaling systems. It is known that the

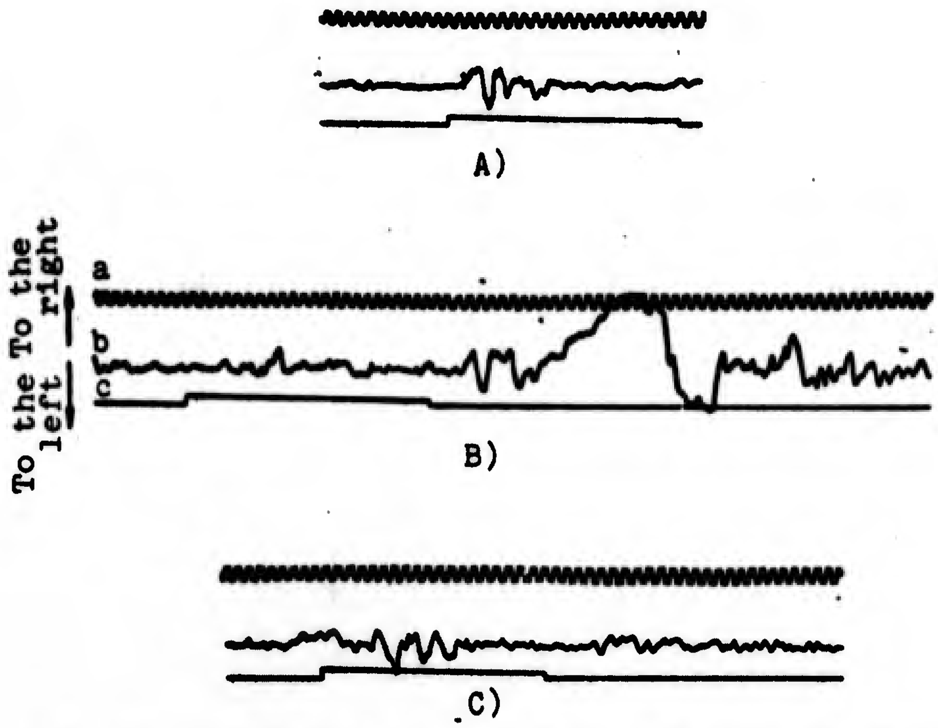


Fig. 39. Tensometeric curve of the body deflections of subject S. A) control – position on an an unstable support; B) motor reaction in the period of the illusion of banking; stimulation of the right vestibular apparatus with a current of 1.5 mA. The eyes are closed; C) the same during fixing of the glance on a burning lamp; a) time of 0.5 of a second; b) the curve of the movements of the torso forward – to the left; c) indication of the stimulation.

analysis of spatial relations in man with the surrounding objects is formed in the process of ontogenesis. This process is carried out by a conditioned reflex mechanism of a different degree of complexity (synthetic, chain conditioned reflexes, stereotype, etc.). Considering the experiment of creating the illusion of banking and the given position, in the experiments various conflict situation were reproduced between the conditioned reflex ideas about the visual vertical and information connected with the sensations of gravitation (by combining the unstable equilibrium of the subject with sudden inclinations of the visual axis or by the use of the so-called "phenomenon of presence" in the period of demonstrating panorama movie images). The subject, sitting in a seat on a shifting support in a state of compensated equilibrium, examined the panoramic films depicting different evolutions (maneuvers) of aircraft (turns, banks, etc). As a result during prolonged stimulations of the visual analyzer (during 1-2 minutes) the "phenomenon of presence" (known in the practice of stereo and panoramic images) was so intensified that in the subject there arose illusions of inverted position, right up to complete loss of spatial orientation. Furthermore, besides disorderly motor activity of the eyes and overall motor reaction, sometimes there appeared expressed vegetative disorders, similar to the motion sickness syndrome and analogous to those, which are observed in flight along a Kepler parabola or possible in astronauts in a state of prolonged weightlessness. In certain subjects depending upon individual peculiarities there appeared dizziness, nausea, and vomiting. Apparently, this is not classical motion sickness, but a peculiar disintegration of the system of complex, synthetic, conditioned reflexes, providing the orientation of man in space. It is not exceptional that this disintegration is caused by the disturbance of the mechanisms of regulation of the vegetative nervous system, on which under conditions of modified afferentation there are presented so many increased demands that crises and vegetative deficiency [39, 246, 248] appear.

The study of causes promoting the inhibition of illusion showed the following: the basis of inhibition is the sense of the vertical, which is composed of two components – sensations caused by the influence of gravitational forces (the gravitational vertical) and visual presentations (the visual vertical). In the first case the basic receptive elements of such sensations are the proprioreceptors, including the sensitive endings of the eye muscles; in the second case the main role is played by visual conditioned reflex reactions connected with the presentations of the location of surrounding objects.

The optimum conditions for inhibition of illusions are created then, when the center of gravity of the subject coincides with the direction of terrestrial gravity, and the visual vertical – with the gravitational. This is observed during insignificant oscillations of the center of gravity with respect to the area of support (within limits of up to 2 mm) and the fixation of the glance on an object located directly in front of the subject at a distance of from 50 to 120 cm along a center line at the level of the eyes. Moreover, the organs of vision, the proprioreceptors of the muscles of the eye, the torso and the vestibular analyzer, constituting a single physiological system, coordinating the reflexes for the motor apparatus, ensure the maintenance of stability and equilibrium.

The coordinated activity of the visual, vestibular and motor analyzers can be disturbed in any section, which is associated with the loss of equilibrium, illusions, and vegetative disorders.

The creation of conflict situations is possible:

– on the part of proprioceptive signalling during movements of the eyes, the attempt to fix the glance on visual objects located at an angle of sight from center line by 30°, and during oscillations of the center of gravity with respect to the vertical with unstable equilibrium above 2 mm;

– on the part of the vestibular analyzer, if its reactions prevail over the possibility of their inhibition with the help of visual and proprioceptive stimulations;

– on the part of the visual analyzer during inclination of the visual vertical and insufficient information, ensuring the correct idea about the gravitational vertical.

What is the mechanism of the vegetative crises accompanying spatial disturbances, it is difficult to say. Certain facts expounded by A. V. Lebedinskiy [139, 141] testify to the participation of the reticular formation in them. Thus, after the administration of Aminazine to rabbits at a dose of 1 mg to 1 kg of weight the vegetative reactions to vestibular stimulations sharply attenated or vanished.

In proportion to the increase of the degree of instability and the increase of sensitivity of the vestibular analyzer the changes of the electroencephalogram reflected a weakening of the activity of the inhibitory processes in the cortex (Fig. 40). Apparently, a similar

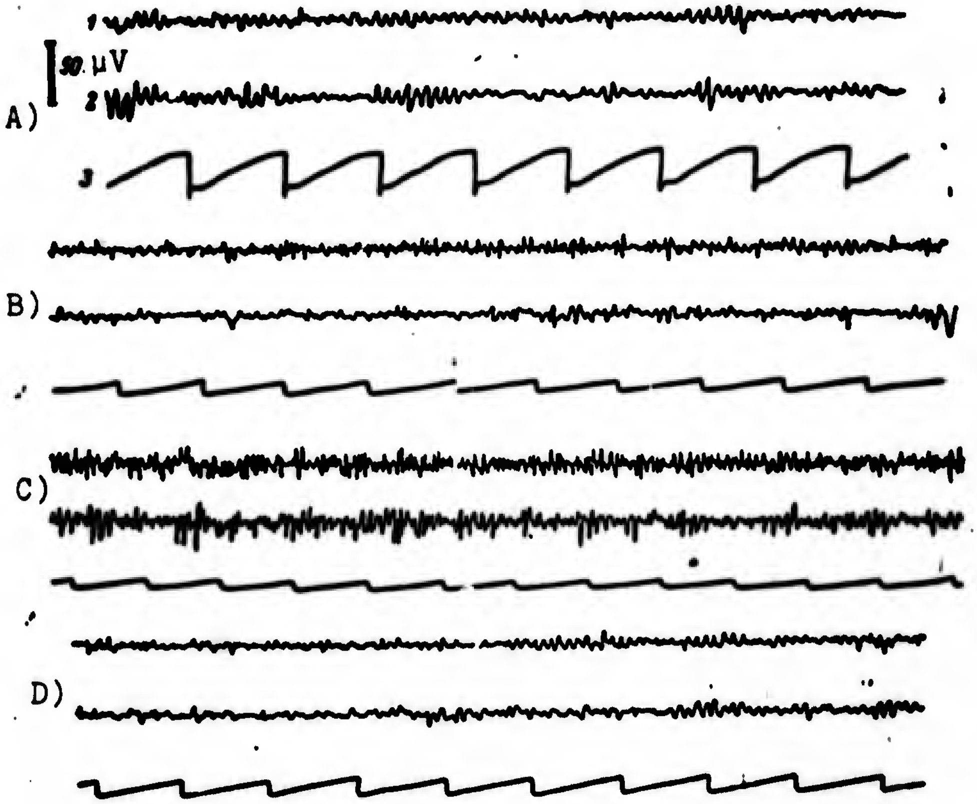


Fig. 40. Recording of an electroencephalogram of subject N. under conditions of balancing. A) in a sitting position on a stable support (control); B) under conditions of balancing on a stable support with an area of 625 cm^2; C) the same on a support with an area of 289 cm^2; D) aftereffect on a stable support; 1 – EEG, temporal tapping; 2 – occipital tapping; 3 – time 1 second.
Designation: EEG = ЭЭГ.

state of the cortical processes facilitated the transmission of excitation from the vestibular centers to the sensory zone of the cerebral cortex and to the vegetative centers. The use of chloral hydrate strengthened the inhibitory processes in the cortex, which promoted suppression to some degree of the sensory and vegetative vestibular reflexes (Fig. 41). Certain elements of interaction of the studied analyzers were characteristically close to the peculiarities of the activity of the analyzer systems in a modified gravitational field.

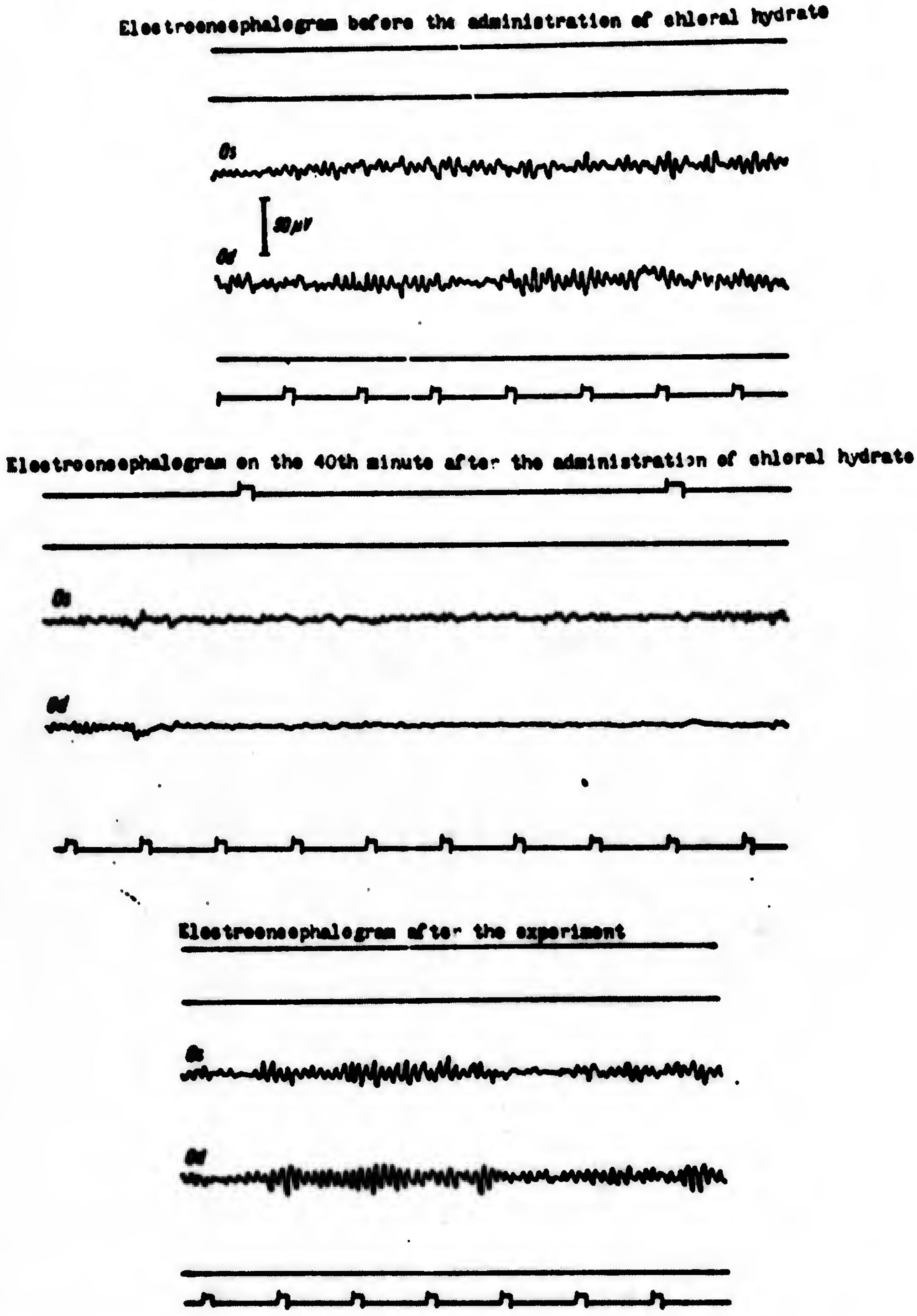


Fig. 41. Electroencephalograms before the taking of chloral hydrate, on the 40th minute after its administration and after the experiment.

The principle distinction in our experiments from those, which were conducted by Graybiel, Clark, and others [296, 297], consisted in the fact that the thresholds of sensitivity of the vestibular analyzer to adequate stimulations were investigated in the dynamics — depending upon the activity of the other analyzer systems and the state of the higher sections of the central nervous system. For appraising the vestibular function there was undertaken an attempt to create the curves of the reactivity of the vestibular analyzer to the vegetative component. With this purpose there was carried out, first, classical cupulometry with a recording of not only nystagmus, but also of certain indices of cardiovascular reactions (arterial pressure, pulse rate, bioelectric activity of the heart). Secondly, into cupulometry there were introduced additions in the form of unimoment inclinations of the head for the purpose of creating Coriolis accelerations. Also studied were vestibulo-somatic reflexes characterizing the tonus of the skeletal muscles. Sensory reactions were considered for the illusion of counterrotation to the sequential visual Purkinje image. The maximum period of revolution equaled 7 days. The angular velocity of revolution varied; the experiments were conducted daily.

The obtained data make it possible to confirm that the vestibular apparatus plays an important role in the development of compensator reactions of organism in the range accelerations, corresponding to tenth parts of the unit of the accelerations.

The most labile during vestibular stimulations is, apparently, the cardiovascular system, in which disturbance of the adaptive reactions occurs by the principle of the decrease of maximum arterial pressure, the increase of the minimum and the decrease of pulse pressure. With sufficient speed of calculation and construction of the corresponding curves with the sensitive diagnostic index of changes of hemodynamics there can serve variation pulsegrams, compiled by taking into account the dynamics of the RR interval on the electrocardiogram.

On the whole the experiments made it possible to connect the development of the adaptational processes to prolonged revolution with the reactivity of the central and vegetative nervous systems of the subjects, where the individual peculiarities played a great role. The latter were detected in the dynamics of the experiment. Thus, standard methods of vestibular expertise did not make it possible to prognosticate the state of subjects under conditions of the prolonged influence of complex accelerations. At the same time the limits of endurable accelerations turned out to be very relative.

Concerning the Extralabyrinthine Symptoms of Motion Sickness

A great role in the mechanisms of the appearance vestibulo-vegetative disorders during the action of accelerations and weightlessness is played by extralabyrinthine factors.

In 1944 V. V. Strel'tsov [225] on the basis of a study of an experiment of the Great Patriotic war turned attention to the circumstance that in otolaryngological expertise physicians collided with contradictory data with respect to the vestibular apparatus; the data were obtained under laboratory conditions and in actual flights on aircraft. According to V. V. Strel'tsov, this discrepancy indicated either the imperfection of the methods of investigating the functional deficiency of the inner ear, or the presence of extralabyrinthine factors leading to the development of motion sickness. To the significance of extralabyrinthine factors in the pathogenesis of disease attention was also turned by V. P. Popov [195-199], A. V. Chapek [261] and others.

What should be understood by extralabyrinthine factors? What is the point of their application? This idea is arbitrary, since anatomically and functionally the vestibular apparatus interacts with the most diverse sections of the central nervous system, analyzers, and internal organs [67, 69, 75, 83, 138, 257, 259].

Irritation of the vestibular apparatus causes a complicated complex of reactions, manifested primarily by vegetative disturbances (intensive peristalsis of the organs of the gastrointestinal tract, nausea, vomiting, diuresis) of various functions of the organism. Along with this the irritation or disturbance of the activity of different organs and their systems can also have an influence on the functional state of teh vestibular apparatus. As a result against the background of its increased excitability a weak or usually inert (for one or another individual) stimulus may cause symptoms of motion sickness. The latter, however, are reactions not direct, but indirect. By extralabyrinthine reactions it is necessary to understand all those functional manifestations, which at first were connected with the increase of the excitability of the emetic center. Intercenter interrelations, according to N. Ye. Vvedenskiy, can under certain conditions accumulate in such a way that the increased excitability of any one reflex center leads to a change of the functional state of other centers: "from the whole nervous system there is obtained a somewhat united whole, in which the smallest change in one part is reflected more or less sensitively and immediately or after a more prolonged interval of time on all other parts" [58]. From the scientific position N. Ye. Vvedenskiy the evolution of neurohumoral regulation of the glands of the digestive system is determined by the development of inhibitory apparatuses in the synaptic structures [145]. According to V. S. Rusinov [212], the interactions between the reflex centers can be accomplished in two ways – primarily the excited center can lower the activity of others or, conversely, can increase their reactivity. Moreover V. S. Rusinov emphasizes, how important it is to consider the initial functional state of the reflex centers, which is caused by some influences: "One single wave of excitation, arriving in the central nerve system, can make its effect felt...on centers very distant from it, if the latter were preliminarily prepared for this by those and other influences" [59, 142].

In a recently issued monograph of V. S. Gurfinkel', Ya. M. Kots, and M. L. Shik [82], dedicated to the mechanisms of regulation of man's posture, there are presented extensive experimental data testifying to the fact that the latent period of vestibulo-motor reactions considerably exceeds the latent period of simple motor reactions. Besides it is emphasized that if the vestibular apparatus has a relationship to the regulation of equilibrium, then the threshold of its sensitivity must be of the order of fractions of an angular minute; in reality the thresholds of perception of angular movements with the vestibular apparatus are considerably higher than those, which are not revealed during comfortable standing. Hence it is also the conclusion of the authors that with respect to sensitivity the vestibular apparatus cannot be direct regulator of body position and the reaction of equilibrium.

In the process of evolutionary development of the functions of the whole organism the specific value of the vestibular apparatus decreases along with its increasing role in the regulation of the posture of other analyzers and primarily of the visual analyzer. "We easily on the basis of optical indications estimate the changes of its position in space and we have little need for the labyrinthine apparatus," – repeatedly emphasized L. A. Orbeli [170].

The special study of the characteristics of vestibular chronazy conducted in our time also revealed the great inertness of vestibular apparatus. Vestibular chronaxy exceeds the chronaxy of the skeletal muscles and the motor nerves by approximately 100 times [67, 68, 287]. The comparatively slight sensitivity of the vestibular apparatus to angular inclinations was established for pilots under conditions of complex flights, which was under investigation even in the 30's [363]. At the same time individual authors [273] continue to examine those or other vegetative manifestations in astronauts under conditions of orbital flight only in connection with the vestibular disturbances arising during weightlessness. Definite value, moreover, is attributed to the thresholds of excitability of the cupula and otolithic apparatuses [273].

The study of the vestibular apparatus, as a rule, was carried out mainly regardless of the connection with the system of the organs of digestion. During the analysis of the interaction of the afferent systems the afferentation on the part of the gastrointestinal tract was insufficiently or absolutely not considered; the pathways of this tract have been well studied. It is known that the pseudounipolar neurons contained in the intramural nervous system, and also second type Dogiel cells are sensitive nervous formations [113, 133] of the reflex paths, both local, along short arcs, as well as general, by which impulsation is transmitted to formations belonging to the vegetative level (limbic region of the cerebral cortex, reticular formation, cerebellum, thalamohypothalamic region). But it is impossible to underestimate the role of the changes of the interrelation between the cortex and the subcortex.

Weightlessness arising after the effect of accelerations, as a physiological stimulus, has an effect on the modified background of the activity of the nervous and humoral-endocrine regulator systems. The new functional level of the state of these reflex centers, and also the state of the functional systems in the whole organism, caused by the totality of preceding complexes of stimulation (pre-launch preparation, transverse-directed accelerations during the take-off of the ship) and the extreme effects accompanying weightlessness (limitation of mobility, modified biorhythm, emotional stress and others) cause the appearance of symptoms of motion sickness. It is obvious that to the same analysis there will also be subject those intersystem functional interrelations, forming in the organism during the state weightlessness, against the background of which influence again is rendered by the transverse accelerations during the entrance of the ship into the dense layers of the atmosphere during the return flight, especially since the values of the accelerations are considerable.

It is known that one of the frequent symptoms of the effect of acceleration in a caudocranial direction is vomiting. In experiments on dogs and apes it was roentgenologically shown that during a acceleration of 5g there appears anti-peristalsis of the stomach and esophagus. Almost in all cases barium sulfate is ejected from the stomach and fills the oral cavity, and in certain cases – the larynx and trachea. In observations conducted on people under flight conditions it has been established that in those cases, when the subject before flight consumed heavy fatty food, at the time of the effect of acceleration in the caudocranial direction it was ejected from the stomach. Moreover, the vomiting was not accompanied by a sensation of nausea. The absence of nausea is so characteristic that this fact can be placed at the basis of differential diagnostics of similar cases of vomiting, i.e., of extralabyrinthine manifestations, from true motion sickness, which is always accompanied by nausea [216].

Thus, individual components, similar to the symptoms of motion sickness, can appear under certain conditions and without a direct connection with the disturbances of the labyrinthine functions. Primarily this relates to such a symptom, as vomiting. In the emetic act there participates somatic and visceral innervation, the coordination of which is carred out by the emetic center, located mainly in the medulla oblongata, but having its representation at all levels of the brain: the reticular formation, the diencephalon, and the limbic region [9, 230, 387, 389]. The general organization of the emetic center, composed Wang and Borison [388], is snown in Fig. 42.

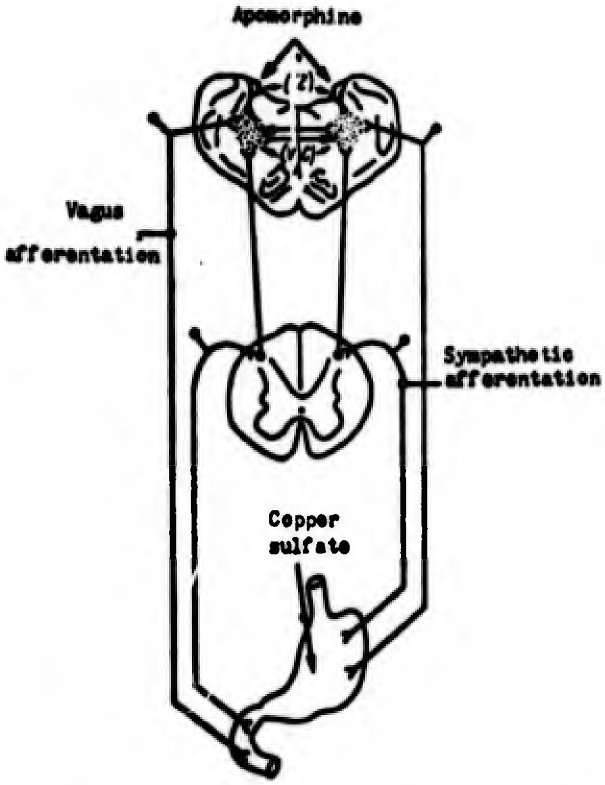


Fig. 42. The structure of the emetic center (according to Wang and Borison). TZ – chemoreceptor "trigger-zone"; VC – emetic center. On the figure there are also represented the afferent conducting paths from the receptors of the gastrointestinal tract.

The motor and secretory components of the emetic act, embracing different sections of the organs of the gastrointestinal tract, were traced in an experiment by V. N. Boldyrev [48], N. A. Rozhanskiy [209], S. I. Chechulin [267], N. N. Lebedev [136], and others. N. A. Rozhanskiy established that at the basis of the motor component lies an anti-peristaltic wave, which starts in the small intestine and spreads to the duodenum and the pyloric section of the stomach.

V. N. Boldyrev examined vomiting as a component element of the periodic activity of the digestive system [48]. N. N. Lebedev in studying the action of morphine observed the course of an anti-peristaltic wave beginning at its place of origin – the terminal ileum. He was able to establish that the biological function of the motor components of periodic activity consist in the evacuation process, also including digestion. The movement of the substrate in the digestive tract in a caudal direction is a very complex process. The evacuation wave arising in the upper section in the gastrointestinal tract does not spread continuously to the terminal ileum. The transmission takes place in group waves, which appear at different levels of the intestine in accordance with distinctions in the mechanisms of regulation. Moreover an assumption was made about the existence "of counter" anti-peristaltic waves, spreading from the ileo-caecal region and transmitting the substrate of evacuation in a caudal direction.

Under conditions of extreme effects changes can be observed in the rhythmic activity of the organs of digestion, promoting the appearance of the emetic reflex. The appearance of periods of stomach contractions, as an amplification of its motor activity, takes place against the background of the attenuation of central parasympathetic influences. In the opinion of N. N. Lebedev, an important role in the mechanism of the origin of vomiting is played by the reflex connections between the terminal ileum and the pyloric section of the stomach [136]. The stimulation of the ileo-caecal region causes a spasm in the pylorus, i.e., it creates in the stomach disposition to the emetic act.

Contractions of the intestine appear earlier than contractions of the stomach, sometimes these reactions are limited only by them. Here, apparently, there appears the so-called intestinal phase of the emetic act which as both a central, as well as a peripheral origin [16, 85, 94]. It has been determined that the intestinal phase of vomiting starts in the first seconds after the administration of apomorphine, whereas the movements of the stomach, abdominal contractions and contractions of the respiratory muscles appear several minutes later or in general, do not appear at all. The intestinal phase of the emetic act always appears as the most stable, obligatory, and first (in time) component of the emetic reflex.

In the mechanism of the appearance of vomiting important significance is possessed by interoceptive signalling from various sections of the digestive tract, the sensitivity of which to the acting stimuli is very diverse [40, 186, 300, 389]. The humoral-chemical factors, stimulating the receptors of the gastrointestinal tract, have an influence on the chemoreceptive emetic "trigger-zone" [368]. However, the paths of the transmission of information from the interoceptors of the intestines are not only nervous, but also humoral-hormonal [16, 387]. In this respect very demonstrative were the experiments carried out by Ye. B. Babskiy [16], A. L. Zak and A. G. Kreatinov [94]: the intestinal phase of the emetic act was observed after the introduction of apomorphine directly into the lumen of an isolated and denervated intestinal loop. There are also data, indicating that after bilateral vagotomy the action of apomorphine is strengthened. On the basis of this the assumption is expressed that normally along the vagosympathetic trunks to the emetic center oppressing influences can arise.

Against the background of the action pharmacodynamic substances increasing the tonus of the parasympathetic section of the nervous system (for example, pilocarpine), the formation of the central emetic act is considerably facilitated [42]. In these cases it is absolutely not excluded that the appearance of vomiting, nausea, and strengthened peristalsis is caused by vegetative crises as a result of the change of the relationships between the parasympathicotropic and sympathicotropic biologically active substances circulating in the blood — the mediators [55, 81, 98, 99, 126, 201]. The mechanism of the emetic action of adrenaline can also be similar. Adrenaline also causes vomiting [368]. Adrenaline is more active than its precursor dopa.

The vegetative crises (probably, hypothalamic) are possible during the effect on the organism of accelerations, leading to expressed changes in the relationships of the content in the blood of parasympathicotropic and sympathicotropic substances. Thus, for rats under the influence of single-acting positive accelerations with a value of 7g and a duration of 1 minute there is revealed a parallelism in the increase of content in the blood of acetyhcholine and adrenaline-like substances. With the value of accelerations of 10g per minute of the relationships sharply change; the content acetylcholine drops almost by 2 times, and the concentration of the adrenaline-like substances increases. During the multiple effects of accelerations the relationships obtain the opposite directivity: the content of acetycholine increases, and of adrenaline - drops. A similar dynamics of the change of relationships is also observed under the influence of decelerations. Certain changes during the accelerations are also revealed in the content in the blood and other tissues of the organism of histamine and serotonin [37, 39, 243].

Thus, in the mechanism of the genesis of extrlabyrintine symptoms of motion sickness during extreme effects great importance is possessed by the disturbances of the reflex connections between different sections of the gastrointestinal tract, on the one hand, and between these and higher centers of vegetative regulation - on the other. It is also safe to talk about the intimate interconnection of the disorders of the motor and secretory periodic activity of the digestive system and disturbances in the metabolism of biologically active substances: acetylcholine, adrenaline, noradrenaline, histamine, serotonin [291, 305, 307, 308, 310, 369, 374, 382].

For a number of secretory motor and trophic functions prolonged aftereffect is characteristic [240]. Individual shifts here, for example changes of the content of serotonin in the blood and in the digestive juices, disturbances of the activity of the enzymes, are detected not at once, but after a certain time [244, 246]. It is not excluded that against a similar background of vegetative disturbances there is also established according to the principle of involvement a new functional level of the vestibular apparatus.

A hypothesis is expressed [392] about the role of histamine in disturbing the microcirculation of blood, explaining certain painful syndromes of the head and neck as a manifestation of Meniere's disease. Inasmuch as the microcirculation of the blood is regulated mainly with the participation of histamine, its excess formation in different tissues of the organism can cause in them a local progressive drop in vasculomotor function, a decrease of sensitivity to adrenaline, reflex dilation of the arteriols, metarterioles and venules with damage to the endothelium, and also an increase of the permeability of the capillaries to large molecules (histamine is formed from local reserves of histidine with the assistance of the enzyme histidine-decarboxylos). The stimulus causing the formation of histamine with a speed exceeding the homeostatic need per unit of the capillary layer, promotes the development of vascular dysfunction [181, 304, 392]. It is necessary to indicate that during accelerations metabolic disturbances also arise in the vestibular apparatus itself [60, 337].

For analysis of the mechanisms of the extralabyrinthine symptoms indubitable interest is presented by the dynamics of the content of serotonin during accelerations - against the background of the lowering of the content of serotonin in the blood there is noted its considerable secretion with the pancreatic and intestinal juices [252]. These changes are examined as a reflection of the overall physiological reaction of the organism to extreme effect and its increased need for the production serotonin [176]. The increased content of serotonin in the upper sections of the small intestine can promote the appearance of the dumping syndrome, which is manifested by nausea, vomiting, and dizziness [136, 201, 215, 251, 280, 301, 303, 343, 339, 370, 373].

Under conditions of extreme effects, against the background of formed intersystem interrelations there are completely possible not only pathogenetic manifestations both of extralabyrinthine, and also of vestibular form, but also disturbances of the overall reactivity of the organism.

From these positions I. M. Khazen analyzes those vegetative disturbances, which were described by the pilot-astronaut G. S. Titov on the basis of introspections. The whole course of events in the organism, preceding the null-gravity state, could bring about by the 6-8th orbit of the flight a new, highly-reactive functional background [246, 248].

The question about the leading role of the vestibular apparatus in the appearance of symptoms of motion sickness in space flight was doubtful from the moment of the appearance of the very idea of a space form of motion sickness [248]. Recently there began to appear critical comments about the necessity for reconsidering the formulated concept. This also resounded to the XV International Congress on Aviation and Space Medicine, with took place in Prague in September-October 1966 (Campbell, Graybiel, and others).

CONCLUSION

PROSPECTS AND PROBLEMS OF SPACE PHYSIOLOGY

Space physiology, on the one hand, strives to use completely the fundamental data of classical biology and medicine, on the other – it takes on itself the latest achievements of biological and technical sciences. Thus, the idea about the cortical and vegetative levels of regulation and their interactions turned out to be very fruitful in application for the analysis of various experimental data obtained under laboratory conditions and in flight. Other concepts of cybernetics, possibly, will also be useful in the discussion of the mechanisms and causality of a number of disturbances caused by the action of extreme factors on the organism. However, the main results of the penetration of cybernetics into space medicine must be the strengthening of the quantitative approach for the analysis phenomena and facts, the mathematization of basic physiological concepts and the introduction of computer and electronic technology into the practical work of the physicians and physiologists. One of the most important directions in this field is the study of the possibility of mathematical prognostication of dangerous states, the appearance of which is possible under conditions of prolonged space flight. The bases of such prognostication are established by investigations, in which the reactions of the organism are described by mathematical expressions, let us assume not very exactly, but very definitely and quantitatively reflecting the connection between the time of the effect and the state of the physiological functions.

The appearance of the computer on board the spaceship, which is a matter of the very near future, confronts the physicians and physiologists with the very crucial problem of the translation of the basic medicobiological ideas, necessary for diagnostics, into the language of figures and codes. The creation of such a language is extremely important; a language by which it would be possible to bring about communication between the physician and the computer. This language undoubtedly will be a product of the joint creative work of representatives of medicine and mathematics. Space physiology is one of the first customers and consumers of a language of quantitative expressions, inasmuch onboard computers, apparently, will be carried out the first attempts to convert from the diagnostics of individual forms of diseases to the diagnostics of the states of man.

Now in space physiology there is most intensively proceeding a study of the reactions of blood circulation, external breathing, and the vestibular apparatus. Rather serious attention is also being focussed on the state of the central nervous system. The most important problem of recent years is the development just such intensive investigations with respect to energy exchange, thermoregulation and digestion. Without similar information about the reactions of these systems of organism it is impossible to make valid recommendations for improving the devices, ensuring the regeneration of air, the conditioning and the thermoregulation in the cabin of the spaceship. These questions are also intimately connected with the solution of problems of nutrition in space flight. Finally, the diagnostics of diseases in the crews of spaceships cannot be at a proper level without a clear understanding of the physiological bases of the vitally important functions of the organism (thermoregulation, energy exchange, digestion, and others). For this first of all it is necessary to develop corresponding methodical procedures, adequate for the conditions of space flight, but then to carry out extensive investigations both in the laboratory, and also in flying experiments with the artificial creation of various proportioned effects.

Energy exchange and thermoregulation, as is known, essentially depend on the conditions of the functioning of the living system. For man, furthermore, the state of the cerebral cortex is very important. Thus, emotional stresses (and in flight there can be many) increase energy exchange not to a lesser degree than work. In general, during weightlessness it is necessary to expect a certain drop of the level of energy exchange and this lowering will be especially expressed during sleep. If it turns out that energy exchange is lowered on the average by 20-30% and more, then this will introduce an essential correction into the designs of systems of lifesupport for spaceships, intended for very prolonged flights.

The digestive system and its neuroglandular apparatus are very sensitive to various extreme effects and they very slowly restore their initial state. These properties of the digestive apparatus should not be neglected in the planning prolonged space flights, since the disturbance of digestion will entail the disorder of the energy exchange and a whole series of complex biochemical and endocrine mechanisms. Therefore, an extraordinarily important question of space physiology is the problem of metabolism in the broad sense of this word from digestion to tissue breathing.

Therefore, biochemical and endocrine investigations, and also the study of the physiological functions on the molecular and cellular level must be recognized as an important direction of the further development of space physiology. This, so to speak, is the line of the deepening of our knowledge in contrast to the line of their expansion, directed towards the study of the reactions of an even greater number of organs and systems. The molecular-cellular level differs by its still greater autonomy from the vegetative level. On the molecular-cellular level there evolve all those basic events, which determine, subsequently the stability of the vegetative and cortical levels to extreme effects. Peculiar to the molecular-cellular level, apparently, to a considerably greater degree than to the other levels, is the ability to accumulate unfavorable influences, the "memorization" and "summation" with the expressed (here) autonomy and inertness. Concerning the most important role of the molecular-cellular level for the organization of any reactions of the integral organism there speaks an experiment investigating the influence of ionizing radiations. Incidentally, radiation constitutes one of the essential factors of space flight, and space physiology must allot to it definite attention, in spite of the existence of a special science – radiation medicine.

The mastering of outer space is connected with the active work of man, first in the cabin of the ship as a pilot and operator, and in the future on the surface of planets. The interaction of man with the environment, and with reference to cosmonautics the interaction of the pilot with the systems of the spaceship lies at the basis of the special level of regulation, which can be called industrial-social, and in a narrower sense is designated by the widespread term "man-machine." On this level there occurs an intense exchange of information between the analyzer-effector systems of man, on the one hand, and the technical systems – on the other. It is necessary to note that the external environment exerts an influence on all levels of regulation: cortical, vegetative, and molecular-cellular. There also exists an exchange of information among these levels and the environment. However, the reactions of the lower levels to the external influences has basically an adaptive-compensator character. Their purpose is the preservation of internal homeostasis. Only the response reactions of the cortical level are active, i.e., they are directed towards the transformation of the environment in accordance with the state and demands of the organism. Only on the "man-machine" level does purposeful creative activity appear, transforming the surrounding world and in the end the organism itself.

The study of the psychophysiological possibilities of man, the questions of the interaction of his analyzer and higher cortical functions with the surrounding conditions and actual technical systems is an important division of space medicine, in the development of which physiologists, psychologists, and physicians are interested. In spite of the presence of the special science of engineering psychology studying systems of the "man-machine" type, many practical and theoretical questions are of great interest for space physiology. In first place is the safeguarding of the optimum efficiency of the astronaut under conditions of prolonged flight, and then the monitoring of efficiency and the early diagnostics of fatigue. It is important to clarify a number of questions, having as yet theoretical interest, but with their positive solution obtaining practical directivity. To such questions it is possible to attribute, for example, the clarification of the possibility of expanding the communications of man with technical systems. Now attempts are being made using the tactile channel for receiving informaiton and biopotentials for the purpose of forming of steering commands. These investigations "lead" the physiologists into the sphere of bionics - a new science about engineering solutions, based on profound knowledge of the principles of organization and functioning of living systems. But this once again emphasizes the comprehensiveness and the manysidedness of space physiology as a new synthetic scientific direction.

The problems of biocontrol also have a relationship to a broader circle of questions. In particular, their solution would introduce a necessary contribution into optimization of the systems of lifesupport on the spaceship, since it would open the possibility of the automatic change of operating conditions of individual sections of the systems of lifesupport depending upon the state of the astronauts. Biocontrol is also necessary for the design of highly-reliable systems of emergency rescue and for improving the conditions of work of the astronaut, for example biocontrol of space suits by numerous motors. The problems of biocontrol also have a close relationship to investigations in the field of anabiosis. The search of the regimes of external effects, used for minimization of physiological funcitons in the introduction into an anabiotic or a state similar to it, would be considerably facilitated by the creation of devices controlling cooling equipment, gas measuring devices or injectors pharmacological substances on given "commands" of different systems of living organism. In actual future systems for anabiosis the presence of biocontrolled subassemblies will be an absolutely necessary condition for their reliable functioning.

It is necessary to emphasize the importance of experiments with animals, simulating future manned flights. These experiments were started long before the first manned flights and will be developed with ever increasing intensity. Interplanetary are in the offing. It is difficult to predict, whether the first interplanetary traveller will be an animal or a man, but it is clear that prolonged flights with animals for biological testing of circumterrestrial space and especially of the radiation belts will be carried out. These flying experiments will demand from the physiologists not only definite programs, intimately connected with the basic problems of space physiology, but also great methodical and systematic preparation. Investigations of reactions on the cortical, vegetative, and molecular-cellular levels can be conducted partially on animals. Animals as bioindicators help to solve questions of the survival of biological specimens under some or other extreme effects. With more detailed investigations with animals it is possible, apparently, to decide problems of biological signalling. Here there is contemplated the selection of such forms of animals, which more rapidly than would reach to some or other factors of flight, thereby warning the astronauts about approaching danger.

The study of the purely human factors of space flight, carried out now within the bounds of the "man-machine" problem, subsequently, will develop into social-law and technical-economic aspects, and also will obtain its development in problems on group psychology. This broad social-industrial level of regulation, on which the social characteristics of man are realized, is not so remote from the interests of space physiology, as it would appear at first glance.

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