

NOTICE

THIS DOCUMENT HAS BEEN REPRODUCED FROM
MICROFICHE. ALTHOUGH IT IS RECOGNIZED THAT
CERTAIN PORTIONS ARE ILLEGIBLE, IT IS BEING RELEASED
IN THE INTEREST OF MAKING AVAILABLE AS MUCH
INFORMATION AS POSSIBLE

GROUND EXPERIMENTS FOR FINDING PRINCIPLES AND WORKING OUT METHODS
FOR PREVENTING ADVERSE EFFECTS OF WEIGHTLESSNESS
ON THE HUMAN ORGANISM

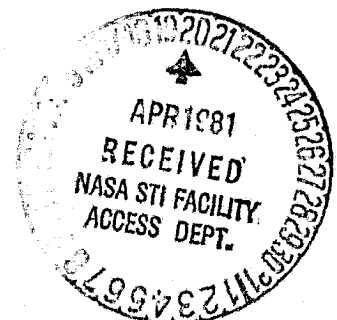
L. I. Kakurin, A. I. Gregor'yev, V. M. Mikhailov and V. A. Tishler
Institute of Medical and Biological Problems, Soviet Ministry
of Health, Moscow

Translation of "Nazemnyye eksperimenty s tsel'yu obosnovaniya
i razrabotki metodov profilaktiki neblagopriyatnogo deystviya
nevesomosti na organizm cheloveka", Report to the XI Joint
Soviet-American Working Group on Space Biology and Medicine,
Moscow, October 1980, pp 1-57.

(NASA-TM-76465) GROUND EXPERIMENTS FOR
FINDING PRINCIPLES AND WORKING OUT METHODS
FOR PREVENTING ADVERSE EFFECTS OF
WEIGHTLESSNESS ON THE HUMAN ORGANISM
(National Aeronautics and Space

N81-21760

Unclas
G3/52 19843



STANDARD TITLE PAGE

1. Report No. NASA TM-76465	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle GROUND EXPERIMENTS FOR FINDING PRINCIPLES AND WORKING OUT METHODS FOR PREVENTING ADVERSE EFFECTS OF WEIGHTLESSNESS ON THE HUMAN ORGANISM		5. Report Date December 1980	6. Performing Organization Code
		8. Performing Organization Report No.	
7. Author(s) L. I. Kakurin, A. I. Gregor'yev, V. M. Mikhailov and V. A. Tishler		10. Work Unit No.	
		11. Contract or Grant No. NASW-3199	
9. Performing Organization Name and Address Leo Kanner Associates Redwood City, California 94063		13. Type of Report and Period Covered Translation	
		14. Sponsoring Agency Code	
12. Sponsoring Agency Name and Address National Aeronautics and Space Admin. Washington, D. C. 20546			
15. Supplementary Notes Translation of "Nazemnyye eksperimenty s tsel'yu obornovaniya i razrabotki metodov profilaktiki neblagopriyatnogo deystviya nevesomosti na organizm cheloveka", Report to the XI Joint Soviet-American Working Group on Space Biology and Medicine, Moscow, October 1980, pp 1-57.			
16. Abstract As the result of many studies both in the USSR and USA the theoretical foundation and experimental demonstration of the effectiveness of physical training combined with NLBP (negative lower body pressure) as prophylaxis against the effects of weightlessness had been established. The authors went further and made a comparative assessment of the effectiveness of different prophylactic procedures in complexes and concluded that: physical training is most effective but no single method by itself produces the full effect and an adjustment of regimes to one another enhances the effect. The approved complex of prophylactic procedures affected basic changes occurring in hypokinesia: deficit of muscular activity, no or reduced BP hydrostatic component, reduced volume of blood circulation, reduced hydration level and the application of various prophylactic complexes during 49 day ANOH (antiorthostatic hypodynamia) eliminated or reduced the adverse effects of weightlessness in simulation.			
17. Key Words (Selected by Author(s))		18. Distribution Statement Unclassified-Unlimited	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price

GROUND EXPERIMENTS FOR FINDING PRINCIPLES AND WORKING OUT METHODS
FOR PREVENTING ADVERSE EFFECTS OF WEIGHTLESSNESS ON THE
HUMAN ORGANISM

L. I. Kakurin, A. I. Gregor'yev, V. M. Mikhailov and V. A. Tishler
Institute of Medical and Biological Problems, Soviet Ministry
of Health, Moscow

1. Introduction

/2*

Experience gained from numerous studies of Soviet and American astronauts has shown that a complex of spaceflight factors and that of weightlessness above all induces in the organism a number of shifts having a negative effect on the feeling of well-being, general condition and work capacity of the crew. Clinico-physiological changes having similar nature and orientation have been disclosed both in laboratory experiments with antiorthostatic hypokinesia (ANOH) and water immersion (WI) which simulated various aspects of the effects of weightlessness, the chief of which, as is well known, are:

- shift of organic fluids toward the upper parts of the body;
- circumscribed motor activity;
- great reduction in the flow of afferent impulsation.

In this context the problem of preventing the adverse effects of weightlessness became clear already 10 to 15 years ago and recently, in a comprehensive amount of Soviet and non-Soviet literature, there have been proposals for a great number of developed procedures and methods for maintaining the astronaut's organism at a high functional level. Many of these have had no time-related verification, but the most feasible and effective ones have been considered in the light of the contemporary data furnished by space biology and aviation medicine in a number of recent works [1-8].

At the same time, the volume increase in programs and the increasing duration of manned spaceflights using large equipment the size of "Salyut" called for an urgent solution to the problem of the selection of the clinico-physiological and technical procedures that would be most real and most useful and might be put to use at once.

Here, in the planning of research efforts, the chief task set up /3 was theoretical analysis and experimental assessment of those resources which could be employed in spaceflights today (physical training, the effect of NLBP, water-salt additives). In addition to all of this the plan was to explore some promising prophylactic measures that would broaden and supplement the positive effect of procedures already being used in the field (electrostimulation of muscles, drugs, etc.).

For a number of years now the chief and most durable device in the entire complex of prophylactic measures has been physical training, the

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

most generally known method for enhancing overall bioresistance in the organism. Its high degree of effectiveness has been demonstrated both in actual spaceflight and in numerous simulation experiments [3, 5, 8]. However, physical training was proven to be effective only in cases where it was sufficiently diversified and aimed at maintaining both speed-strength tolerance and general tolerance when energy expenditure is 400-450 kcal/hr. In addition, it became clear that a very important feature is the cyclic quality of physical training, the optimal formula being 3+1 and training periods lasting 2 hr/day.

At the same time there was recognition of the need for final verification of the training programs developed in testing and combined research so that a final judgement could be made in respect to their use on board the orbiting station "Salyut".

A procedure that was very helpful prophylactically and generally /4 accepted in space medicine was the NLBP (negative lower-body pressure) that made it possible, under weightless conditions, to produce fluid transfer in the human organism [7, 9]. The positive effect of this method on a number of hemodynamic indices and particularly upon orthostatic resistance was established in hypokinesia [10]. Meanwhile the answer still was missing to the question of NLBP effectiveness when the length of time spent in spaceflight changed, including its value as part of a complex of other prophylactic procedures. Moreover, in view of the possibility that collapse might occur with the use of the NLBP [11] it was highly desirable that a usage program be worked out that would be safe and yet sufficiently effective.

Another subject for further study is the condition of water-salt exchange as well as renal functioning in weightlessness [12-13]. This is conditioned by a close link between the metabolic processes referred to and the hemodynamic state of the organism. For this reason we provided for an experimental basis in respect to the procedures aimed at correcting water-salt balance in the organism and, as part of this, compensation for the amount of intravascular fluid.

The experience of clinical medicine and of a number of its applied fields shows that the functional potential of the organism may be heightened by appropriate drugs. In respect to medical care on spaceflights, recent years have witnessed attempts, often quite successful ones, to employ pharmacological preparations for neutralizing given negative reactions in the organism that develop as the result of weightlessness and hypokinesia. Thus, there can be no doubt about the basic importance of studying the use of drugs in individual instances of spaceflight [14].

The report presents materials from experimental studies providing a basis for recommendations as to the working out of prophylactic measures for manned flights on the station "Salyut-6". Only such methods of combatting beforehand the adverse effect of weightlessness on the human organism, or in the broad sense methods of maintaining the astronauts' health and work capacity, as could meet the basic requirements of effectiveness and convenient application were studied in detail. /5

The research pattern comprised the following parts which even today have not lost their great importance for the science of space aviation:

1. Study of reactions and conditions induced by weightlessness and by other spaceflight factors.
2. Laying down the base for a basic experimental model of weightlessness.
3. Clarification of the nature of functional disturbances.
4. Laying down the pathogenic principles required for the elaboration of prophylactic methods.
5. Assessment of the effectiveness of a prophylactic method under ground conditions.
6. Working out optimal programs for the use of a concrete method of prophylaxis (duration of the effect, intensity, sequence, cyclic pattern) as applied to spaceflight apparatus.
7. Setting up a complex of prophylactic measures for spaceship 6 crews.

In previous joint meetings of the Soviet-American work group a complete discussion was held on physiological reactions in weightlessness or in simulation of its effects in ground studies, so this report is a concise presentation of information on the effectiveness of prophylactic methods (3-5 directions of research).

Here the type of evaluative criteria used were mostly those physiological indices and those functional loading tests that are used by Soviet and American specialists in checking the condition of astronauts prior to orbital flight, after flight and in the case of volunteers used for ground studies.

The methodology for conducting tests of physical load on the velogomerer, using NLBP, orthostatic action and water loading, was, as we know, the subject of special consideration in the joint meetings and, as a result of the agreement reached, the identical methods were used in the Soviet-American hypokinesia experiment. Without substantial alteration the functional tests became part of the program for monitoring members of the "Soyuz-Salyut-6" crews.

It is natural that one report cannot possibly present all the material gathered in recent years on the problem of prophylaxis in space medicine. We have limited ourselves to the most important information. The report pays special attention to prophylaxis of the cardiovascular system, water-salt exchange and renal function, points which it is commonly agreed may be the limiting factor for human sojourn on spaceflights.

2. Research Method

7

2.1. Planning Experimental Studies

For determining the practical scope of these studies we worked out a plan for setting up a scheme whereby the first order of business would be approval of those prophylactic procedures that might find practical application in actual spaceflight.

In the first study stage we proposed to examine the effectiveness of individual prophylactic procedures. With this in view part of the study was devoted first of all to a preliminary evaluation of the effectiveness of some prophylactic procedures in lab experiments during 14 days of ANOH subsequently checked out on the basis of 49 day simulation of ANOH.

At the second stage we ran an experimental check of the effectiveness of two or more prophylactic procedures in combination.

In the third and final stage we set up and assessed various groups of prophylactic methods. This sort of program structure made for an assessment of each of the procedures used for the purpose of creating a single system of prophylactic and rehabilitative procedures.

2.2. General Research Conditions

Participants were male volunteers, preferably up to 35 years old, passed by a special review board and declared in practical good health. They were kept in a hospital where their daily timetable was strictly supervised. During the background period (BP) no strictures ⁸ were put upon motor activity. During the time subjects were prepared for their experimental activities and tested for initial physiological characteristics.

During the experimental period a study was done of the effectiveness of various prophylactic procedures on the human organism. During the time the subjects followed an ordinary motor regime (lab tests) or were subjected to limitations of their motor activity (simulation studies). During experimental study using ANOH as an experimental model of weightlessness the motor activity of the control group (CG) was reduced to the minimum, while the experimental group (EG) were subjected to partial conditions of prophylaxis. In a number of the studies on days 2, 3 and 42 of ANOH a more thorough study was made with the use of functional tests -- orthostatic dosing of physical work on the veloergometer in a recumbent position.

All subjects were kept on a standard diet ration of staple foods. The general calorie count was about 3500 kcal/day. No limit on fluids.

2.3. Research Methods

In order to standardize the methods for evaluating the effectiveness of prophylactic measures we determined the range of the required complex of parameters and functional tests to be carried out for a 49 hour ANOH study. The methodology was worked out and unified as well as a standard research cyclogram. In particular, when choosing research methods, the chief emphasis was on those parameters and functional tests which are currently in practical use for clinico-physiological monitoring of astronauts. /9

There was continuous monitoring of the subjects' state of health by physicians. The following studies were done:

2.3.1. Examination by specialists (therapist, otolaryngologist, oculist, neuropathologist) using accepted clinical methods.

2.3.2. Clinical study methods (measurement of body temperature, pulse rate, respiration rate, BP, body weight, amount of fluid taken in and excreted, clinical analysis of blood and urine, biochemical study of blood and urine, EKG).

2.3.3. Functional tests:

- passive orthostatic test (POT), remaining for 20 min in the vertical position at an angle of about 75°;
- effect of negative pressure on the lower body (NLBP) at these vacuum values: -25 mm Hg for 2 min, -35 for 3, -40 for 5 and -50 for 5 min.

- test with dosed physical load (DPL) at a power of 100 w (612 kg/min) for 7 min done on the veloergometer in both recumbent and sitting position;

- test with maximal physical load (MPL) on the veloergometer until subject is completely exhausted and unable to continue.

Special studies were carried on in addition to the required group of parameters and functional tests.

/10

...[lacuna] tests and MPL

In accord with the basic goals of the research project -- working out effective procedures to prevent reduction of orthostatic resistance and diminution of physical work capacity -- we used as the basic criteria for effectiveness the results from our assessment of tolerance to the orthostatic test or the NLBP as a reflection of the stability of the human organism in respect to gravitational redistribution of the blood and functional tests with MPL used as the basis for evaluating physical work capability.

A single system of unified evaluations, despite its complexity and imperfections, should, in the first place, give an idea of the initial condition of the subjects and, in the second place, furnish a picture of the changes occurring as the result of experimental or

flight factors. Here tolerance to the test was evaluated on the basis of a point count ranging from 100 (best) to zero (worst). Each parameter included in the test was assigned a "value coefficient".

In evaluating the orthostatic test we used as tolerance criteria the following indices:

- maximum pulse rate in vertical position;
- maximum pulse rate increase in vertical as compared with horizontal position;
- minimum value for pulse BP in vertical position;
- maximum drop in same when changing from horizontal to vertical;
- time when fainting sets in.

Results of calculations based on the scheme worked out indicate that a test subject presenting good tolerance in the orthostatic test receives high points (60 and above), for satisfactory tolerance average points (59 down to 40) and with poor tolerance low points (39 down). (Table I).

TABLE I. RANKED EVALUATION OF HUMAN CVS REACTION TO ORTHOSTATIC EFFECT /11

Points	Indices and their "weight value"			
	Pulse rate (beats/min)	Δ Pulse rate (beats/min)	Pulse BP (mm Hg)	Δ Pulse BP (mm Hg)
	0,5	0,2	0,1	0,1
100	50	0	60	0
99-90	51-60	I-10	59,5-55,0	0,5-5,0
89-80	61-70	II-20	54,5-50,0	5,5-10,0
79-70	71-80	2I-30	49,5-45,0	10,5-15,0
69-60	81-90	3I-40	44,5-40,0	15,5-20,0
59-50	91-100	4I-50	39,5-35,0	20,5-25,0
49-40	101-100	5I-60	34,5-30,0	25,5-30,0
39-30	111-120	6I-70	29,5-25,0	31,0-40,0
29-20	122-140	72-90	24,5-20,0	40,5-45,0
19-10	142-160	92-110	19,5-15,0	45,5-50,0
9-0	162-180	112-130	14,0-5,0	51,0-60,0

Note: In this and further tables read comma as decimal point and I as 1

TABLE II. RANKED EVALUATION OF FUNCTIONAL POSSIBILITIES FOR THE HUMAN/12
CVS BASED ON RESULTS OF MAXIMAL PHYSICAL LOAD TEST

Points	Indices and their "weight value"			
	V O ₂ (ml/min)	V O ₂ body wt (ml/kg/min)	O ₂ - pulse	O ₂ use ml/l inhal.
	0,3	0,4	0,2	0,
100	4500	66,0	25,0	45,
99-90	4450-4000	65,2-58,0	24,6-21,0	44,5-4
89-80	3950-3500	57,4-52,0	20,7-18,0	39,5-34,
79-70	3480-3300	51,6-48,0	17,9-17,0	34,8-33,
69-60	3280-3100	47,6-44,0	16,9-16,0	32,8-31,
59-50	3080-2900	43,6-40,0	15,9-15,0	30,8-29,
49-40	2880-2700	39,6-36,0	14,9-14,0	28,8-27,
39-30	2680-2500	35,6-32,0	13,9-13,0	26,8-25,
29-20	2480-2300	31,6-28,0	12,9-12,0	24,8-23,
19-10	2280-2100	27,6-24,0	11,9-11,0	22,8-21,
9-0	2080-1900	23,6-20,0	10,9-10,0	20,8-

To evaluate reaction of the cardiorespiratory system when the subjects were given the MPL test we used as criteria of tolerance the following indices:

/13

- maximal oxygen requirement;
- maximal oxygen consumption per unit of body weight;
- oxygen pulse;
- coefficient of oxygen consumption (Table II).

Results of calculations based on the given scheme indicated that the largest number of points (70 and more) went to trained males and in particular those engaging in strenuous sport, the medium number of points (40-69) went to nontrained persons who lead an ordinary life and the lowest number of points to those with varying degrees of de-training or the CVS bordering on the pathological.

It should be noted that the proposed variations on unified evaluations may also have some disadvantages associated with the division among the most informative indices and the determination of the "value

coefficient". Nonetheless, we thought it possible to present the results of the evaluations that had been worked out and this for the purpose of a more widespread discussion and further improvement on the basis of further experimental research.

3. Research Results

/14

3.1. Physical Training

On the basis of an analysis of the literature data and also of previous studies the following principles were suggested for setting up physical training under ANOH conditions [3, 5 18];

- continuity (systematic type of training throughout hypokinesia);
- replicability of training loads;
- gradual increment of load;
- comprehensive effect on the organism;
- cyclic character of training exercises.

Subjects did their physical training on a combination athletic trainer (KST-2) that simulates biking, rowing and also provides stop-and-go loading (walking, running, jumping). In simulated biking on the velocipede the subject turned the pedals at a rate of 60 rpm and a velocity load of 90 rpm. Rowing was simulated by alternate use of two drive levers. Stop-and-go activity was obtained with a rubber band connecting with a movable cradle and frame.

Training was aimed at maintaining basic physical qualities: strength, speed, endurance, preservation of physical work capacity and of motor habits (walking, movement coordination). Training during ANOH comprised a 4-day cycle with a preferential orientation given to the loading on each day of the cycle:

- day 1 - maintaining strength and speed-strength qualities;
- day 2 - maintaining muscular endurance;
- day 3 - maintaining overall organic endurance;
- day 4 - rest.

/15

Energy expenditure fluctuated in the range of 300-400 kcal/hr. Subjects trained twice a day for 60-65 min. Training followed this pattern: massage, 5-8 min; main section, 40-50 min (pedaling, rowing, stop-and-go loading); termination (Fig. 1) - 5 min.

In the opinion of the subjects the training gave them satisfaction, was easy to take, created a pleasant feeling of fatigue that extended to the next exercise in line (Table III). Pulse reaction to an equivalent amount of loading at the end of the ANOH was less than on the first days. Subject weight loss due to training after 30 days of the ANOH dropped by 30-50% when compared with the first training cycles. The results furnish ground for the opinion that the proposed structure for a group of physical exercises and the amount of load appeared adequate for the functional potential of the organism of the subjects and is determined physiologically (Fig. 2).

"Page missing from available version"

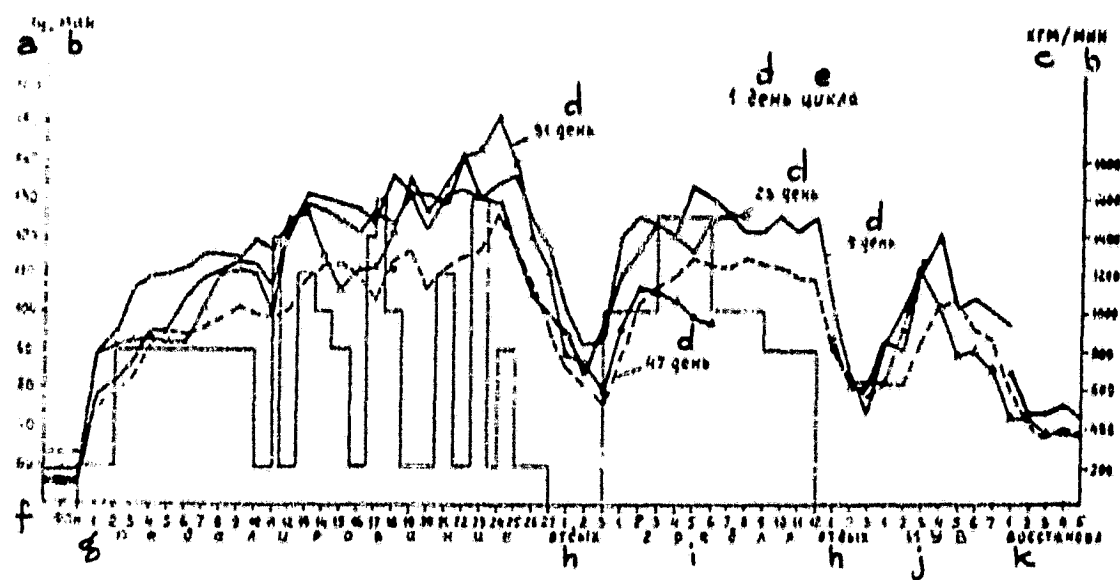


Fig. 2. Cardiac contraction rate (beats/min) on day 1 of the cycle of 49 day antiorthostatic hypodynamia. Legend: ----- 9 days, -o-o-o- 23 days, -Δ-Δ-Δ- 31 days, - . - . - 47 days ANOH.

- Key:
- a. beats
 - b. minute
 - c. kilogram
 - d. day
 - e. cycle
 - f. background
 - g. pedaling
 - h. rest
 - i. rowing
 - j. stop-go
 - k. recuperation

The first day following termination of the ANOH leg volume of control subjects dropped on the average by 540 cm³, while for the experimental group it was smaller by 153 cm³. In this situation the reduction for the control group was observed both in respect to the volume of the lower and upper leg (226 and 314 cm³ respectively) whereas in the experimental group the increase was limited to the lower leg (168 cm³), the upper leg showing on the average a value close to the initial one. On day 2 of recuperation leg volume had practically returned to normal for the experimental group, although that of the upper leg was higher than the initial figure, whereas for the control group the volume of the lower and upper leg remained reduced (Fig. 3).

Muscular strength in the shoulders of both groups following ANOH remained at a level close to the initial one or was even slightly higher. The strength in the extensors of the lower leg, upper leg and torso went down in the control group but in the experimental group these changes were less pronounced: on day 3 of the recovery period the strength of individual muscles in the experimental group had returned to the initial level, while in the control group these indices remained diminished even to day 11 of the recuperation period (Fig. 4).

TABLE 3. DYNAMICS OF PULSE RATE AND BODY WEIGHT FOR 6 SUBJECTS IN EXPERIMENT WITH PHYSICAL TRAINING DURING 49 DAY ANOH (AVERAGE FINDINGS FOR A SINGLE 4 DAY CYCLE)

Days in ANOH	1-6	7-10	11-14	15-18	19-22	23-26	27-30	31-34	35-38	39-42	43-46	47-
Cycle	I	2	3	4	5	6	7	8	9	10	11	12
Pulse rate, rest	74	71	66	70	74	71	70	69	70	75	72	70
Pulse rate, maximum	I42	I31	I23	I26	I33	I20	II8	II7	II6	II0	II2	II:
% of maximum pulse rate	91	84	86	80	79	68	68	69	65	46	55	4'
Weight loss, in grams	617	379	456	501	590	559	626	475	313	405	355	43
% weight for first cycle	-	-39	-27	-19	-5	-10	+1	-24	-50	-35	-43	-3

ORIGINAL PAGE IS OF POOR QUALITY

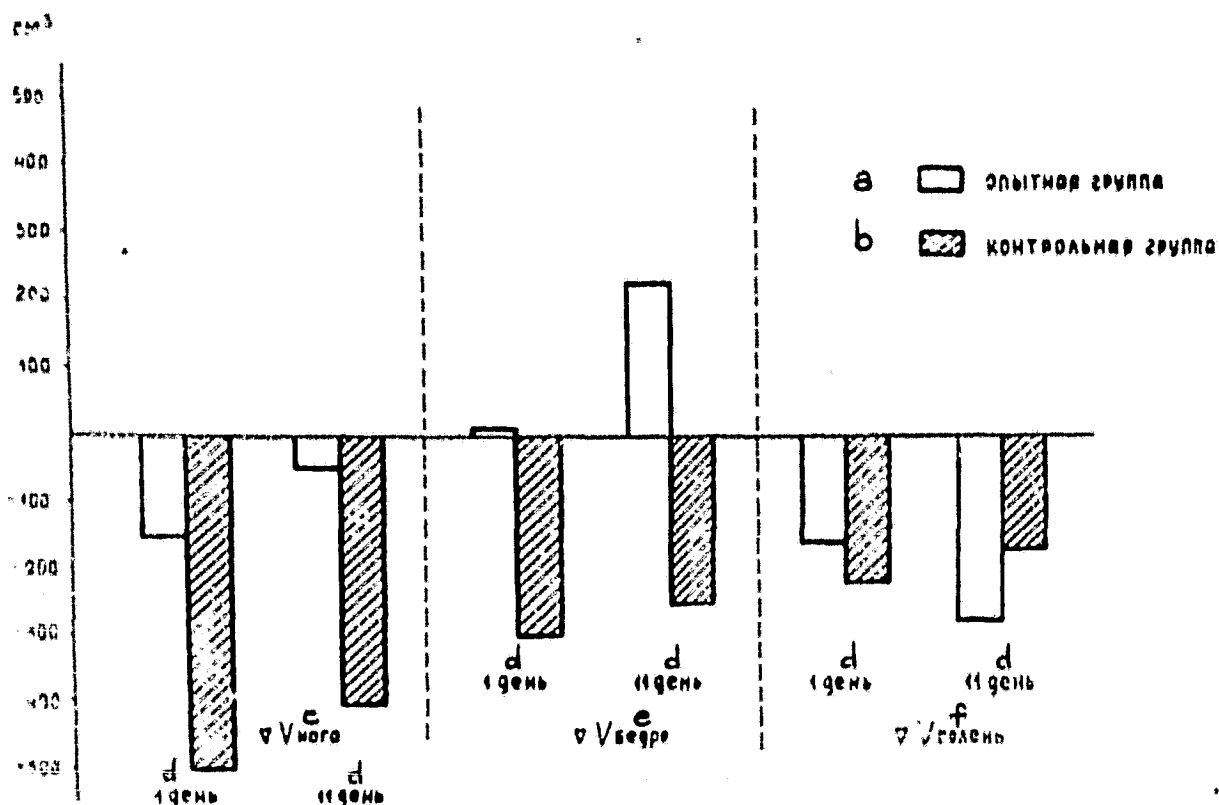


Fig. 3. Changes in volume of leg (cm^3) (upper and lower) in subjects after termination of 49 day antiorthostatic hypokinesia (ANOH). Legend: 1) clear columns - physical training group (6 in number), shaded columns - control (also 6); 2) day 1, day 11 after end of ANOH compared with background.

Key: a. experimental group d. day
 b. control group e. upper leg
 c. leg f. lower leg

The average amount of reduction in the tonus of the anterior tibial muscle in the control subjects as shown by the Sirman myotonometer during the first day of the recovery period was 15 units, while for the experimental group it was only 10.8 units. In both groups (Fig. 5) changes of tonus in the quadriceps femoris and biceps humeri were minor.

Changes for walking parameters after ANOH were more distinctly noted in the control group. Step length went down from 680 to 617 mm, while in the experimental group the drop was minimal -- 765 to 759.

The rheobase and chronaxia of the biceps humeri underwent no substantial changes in either group with ANOH, while the quadriceps femoris enlarged considerably in the control, evidence of reduced excitability. In the experimental group it remained as initially (Table IV).

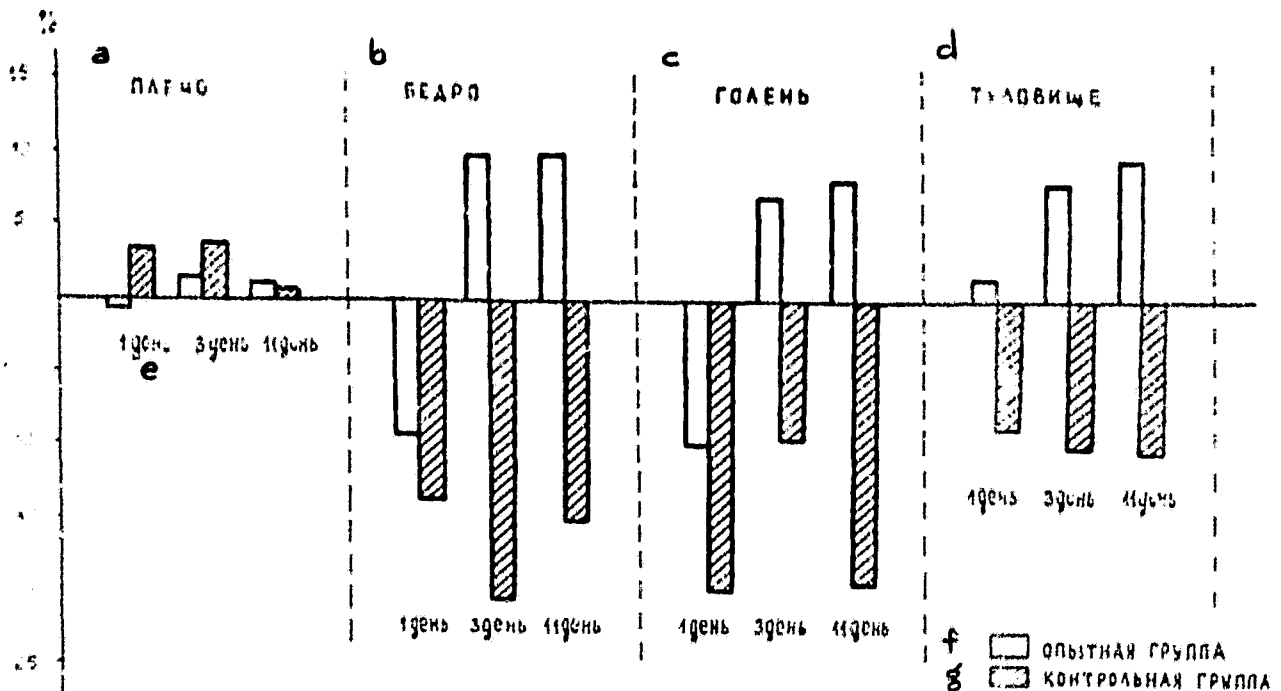


Fig. 4. Changes in strength (%) for muscles of the shoulder, upper leg, lower leg and torso in subjects after termination of 49 day antiorthostatic hypokinesia. Legend: 1) clear columns - physical training group (6 in number, shaded - control group (also 6); 2) day 1, day 3, day 11 - corresponding days of recovery period (after ANOH) compared with background.

Key: a. shoulder e. day
 b. upper leg f. experimental group
 c. lower leg g. control group

ANOH exhibited a more pronounced effect on the functional mobility of the neuromuscular apparatus in the control group than on its excitability, as evidenced by the substantial reduction in the optimal and maximal rhythm not only in the lower extremities but also in the upper. In the experimental group there was a very insignificant drop in functional mobility of the neuromuscular apparatus in respect to optimal and maximal rhythm.

A soleus biopsy done on 6 members of the experimental group indicated that the amount of sarcoplasmic and contractile proteins was being maintained at the initial level as well as their enzymatic activity.

Orthostatic resistance had gone down, particularly in the control group: 3 of the 6 fainted and cardiac contraction rate in the vertical position rose to 126/min as compared with 79 in the background studies. In the experimental group only 1 of the 6 fainted and cardiac contraction in the vertical position rose to only 114/min as against 106 in the background studies.

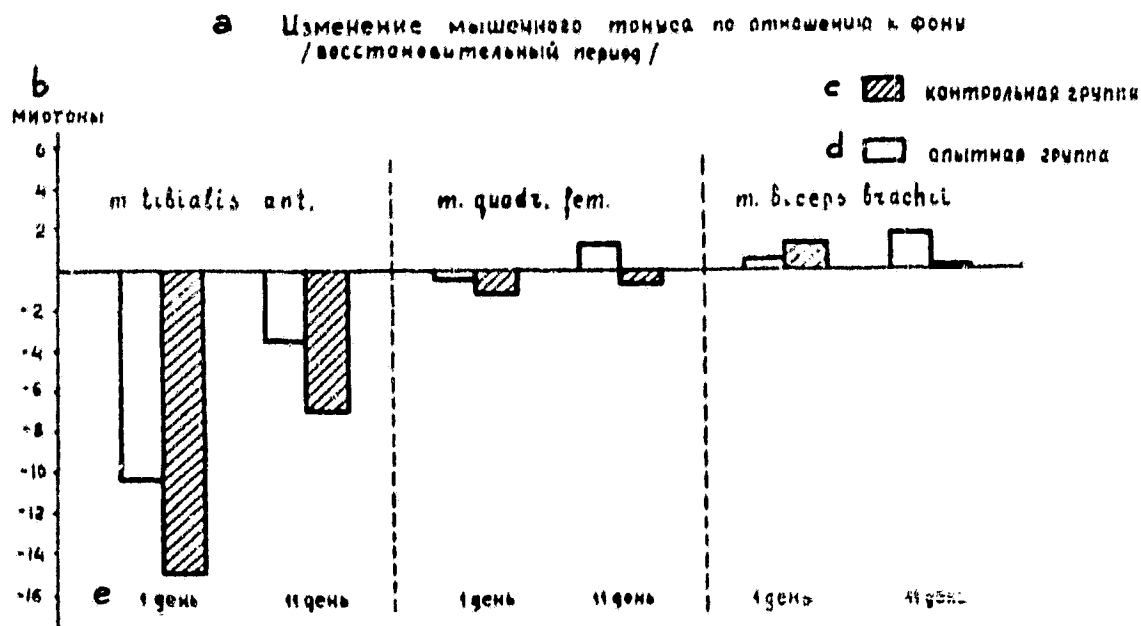


Fig. 5. Change of muscular tone (in myotones) of subjects after termination of 49 day antiorthostatic hypokinesia. Legend: 1) clear columns - physical training group (6 in number), shaded - control group (also 6); 2) day 1, day 11 - corresponding days of recuperative period (after ANOH) compared with background.

Key: a. change in muscle tone in respect to background /recuperative period)
 b. myotones
 c. control group
 d. experimental group
 e. day

The maximal physical load test, taken on the first day following termination of the ANOH revealed complete retention of physical work capacity in subjects of the experimental group and a substantial diminution in the control. In the experimental group the volume of work carried out even went up a bit from 6889 to 7715 kg after termination of the ANOH and oxygen consumption mounted from 2.8 l/min to 2.95 respectively.

In the control group the work volume dropped from 14,244 kg in the background studies to 9064 after termination of the ANOH and oxygen consumption went down from 3.5 l/min to 2.29 respectively.

The proposed physical training program as an individual method of prophylaxis did not completely assure maintenance of the initial level of orthostatic resistance, static tolerance, body stability in a complicated vertical attitude or lower leg volume. We must assume that for the retention of these qualities and especially orthostatic stability there is needed a combination of physical training and other prophylactic procedures. However, the proposed training program did

TABLE IV. DYNAMICS OF STIMULATION INDICES AND MOBILITY OF QUADRICEPS FEMORIS AND BICEPS HUMERI IN SUBJECTS OF EXPERIMENTAL AND CONTROL GROUPS AGAINST BACKGROUND AND ON DAY 47 OF ANOH

Indices	group	quadriceps femoris			biceps humeri		
		background	day 47	%	background	day 47	%
Rheobase (volts)	exper	21,2	21,3	+0,5	9,7	9,5	-2
	contr	19,3	37,7	+95	11,6	14,4	+24
Chronaxia (milliseconds)	exper	0,048	0,049	+2	0,041	0,036	-12
	contr	0,035	0,046	+31	0,026	0,03	+15
Optimal stimulation regime based on retention for 1 second in imp/sec	exper	45,2	45,5	+0,7	53,3	51,3	-4
	contr	54,7	27,5	-49,7	52,4	38,4	-26,7
Optimal stimulation rhythm based on retention for minimum time interval (imp/s)	exper	89,2	84,2	-5,7	100,0	93,3	-6,7
	contr	105,9	50,0	-52,8	102,4	61,9	-39,6
Maximal stimulation rhythm based on retention for 1 second in imp/sec	exper	137,2	135,0	-8,9	149,7	136,1	-9,1
	contr	150,2	72,3	-51,9	152,5	81,4	-46,6
Maximal stimulation rhythm based on retention for minimal time interval in imp/sec	exper	187,2	168,3	-10,1	196,3	180,5	-9
	contr	194,7	98,8	-49,3	195,0	110,0	-43,6

assure retention of basic physical qualities, maintenance of kinematic characteristics and steady gait, excitability and lability of the neuromuscular apparatus, physical work capacity when maximal effort was put out on the veloergometer, retention of the amount of sarcoplasmic and contractile proteins and their enzymatic activity in the soleus muscle.

On the basis of the data obtained one may recommend the program worked out for physical training as part of a complex of prophylactic procedures.

3.2. Electrostimulation of Muscles

/21

The present report gives a summary of the results gotten with myoelectrostimulation (MES) as a prophylactic against atrophy of the skeletal muscles and other disorders developed by a healthy person in prolonged experimental hypokinesia. In line with special conditions methods were developed for multichannel peripheral MES and small portable electrostimulators, prototypes for the onboard "Tonus-2" (Fig. 6).

Evaluation of MES effectiveness was done in laboratory and simulation studies over a 49 day period. In the former there was testing of the Tonus-2 apparatus and refinement of the MES routines. In the latter we assessed effectiveness of the MES in hypokinesia. Along with accepted methods for evaluating MES effectiveness there was first-time use of the direct method -- muscle biopsy for structural and histochemical analysis of muscle fiber. Table 5 (16-18) presents the general conditions of the experiment. In all experimental series with MES the muscles examined were those of the legs, back and abdomen (8 groups of muscles).

The MES was not successful in averting the negative effect of hypokinesia but, when compared with the control group, its influence may be looked upon as positive. Subjects treated with MES subjectively stood the conditions of hypokinesia much better than those not subjected to stimulation. The sessions were perceived as pleasant experiences as long as they did not exceed 15-20 min. Residual feelings were reminiscent of the aftermath of light physical work or a massage. /23

In all experiments the method exhibited a positive effect on tone and muscular strength indices and promoted retention of nearly the initial volume for the muscle mass in the legs. Thus, while in subjects of the control group (3 and 5 study series) muscular tone went down 13-25% toward the end of the experiment, the same index did not drop more than 10% for subjects treated with MES. The picture was similar in regard to retention of muscular power (standing power) and perimeters of the legs.

In the assessment of prophylactic effect special importance was assigned to data from functional tests to determine organism resistance to random physical loads of a cyclic and static type. Results obtained indicated that following the course of the MES there was a substantial increase of muscular work capacity in an isometric pattern: static load endurance time increased in all subjects irrespective of whether

"Page missing from available version"

TABLE V. BASIC CONDITIONS FOR EXPERIMENTS
IN MYOELECTROSTIMULATION (MES)

Criteria	Motor activity program for test subjects	Purpose of the study	Duration in days	Number of subjects	MES program
1	Random out a methodology and MES schedule	Working out methodology and MES schedule	30	6	5 x/wk (1/day for 20-30 min)
2	Random	Test of "Tonus-2" apparatus, work out methodology	30	10	Daily once for 15 min (5 subjects); daily once for up to 90-120 min (also 5 subjects)
3	BR in antior-thostatic attitude (-4°)	Assessment of MES effectiveness	30	3	6 x/wk (twice/day 30 min each time)
4	as above (-7°)	same	45	8	Twice daily for 20-30 min ea time
5	as above (-4°)	same	49	6	6 x/wk (once daily 15-20 min ea time joined with physical training on veloergometer); energy expended in work 450-500 kcal/day

Note: in all experimental series MES used on muscles of legs, back and abdomen (8 groups of muscles).

ercises reduce loss in the soleus muscle of sarcoplasmatic proteins; at the same time their enzymatic activity is reduced. In strict BR conditions for the control group, on the contrary, we note a decrease in the amount of these proteins and augmented enzymatic activity [21].

In the fifth study series trained subjects succeeded in retaining their physical work capacity practically intact, while in the control group it dropped by about 40%. However the combination of physical training and myoelectrostimulation was not enough to maintain orthostatic stability. Following termination of the ANOH two subjects in the experimental group showed a precollaptoid condition during the orthostatic test and the others presented a pulse rate higher than in the background studies, while their pulse BP was lower.

TABLE VI. EFFECT OF MES ON DYNAMIC AND STATIC ENDURANCE

/26

Series	Group	Volume of work done in maximum physical load test on veloergometer* (in % of initial level)		Tolerance of static load** (in % of initial level)	
		control	MES	control	MES
1		-	-	-	136
2	MES-15***	-	107	-	128
2	MES-120***	-	115	-	134
3		63	79	76	152
4		61	68	86	140

Note: * - test with maximum physical load (MPL) began at 600 kg/min and by the minute increased by 200 kg/min until subject was totally exhausted;

** - static endurance - maximum muscular isometric tension time (muscles of legs and torso) in holding standard load at required height;

*** - MES-15 - 15 min stimulation session, MES-120 - 90-120 min session

TABLE VII. PULSE RATE FOR 15 MIN ORTHOSTATIC TEST BEFORE AND AFTER TERMINATION OF BED REST

Series	Control			MES		
	Before hypokinesia	After	Δ	Before hypokinesia	After	Δ
3 (39 days BR)	87	126	39	79	98	19
4 (45 days BR)	81	150	69	80	125	45
5*) (49 days BR)	87	136	49	82	124	42

*) In series 5 the MES was combined with physical endurance training.

In trying various MES routines in order to select the most optimal ones (study series 1 and 2) we hit upon two points worthy of note: in the first place, as a rule when the session ran longer than 15-20 min discomfort phenomena began to manifest themselves; in the second place, a session longer than 15 min (30, 90, 120 min) added nothing to the effectiveness of the training. We therefore decided to limit sessions to 15 min each.

Thus, we may conclude that MES has a positive effect on the muscular system (tonus, working capacity of muscles in an isometric program, prevention of atrophy, maintenance of strength). The method is not as effective in preventing changes in the CVS under the influence of hypokinesia.

3.3. Negative Lower Body Training (NLBT)

/28

The goal of the studies was to work out feasible and safe training programs using NLBT and to draw up recommendations that they be approved for group studies. In order to meet these goals we conducted 6 series of experiments employing 30 subjects aged 21-36 who had been in ANOH for 14 days.

6 subjects (series 1) were trained daily with NLBT for the last 5 days of ANOH following a routine presented in Fig. 7.

/28a

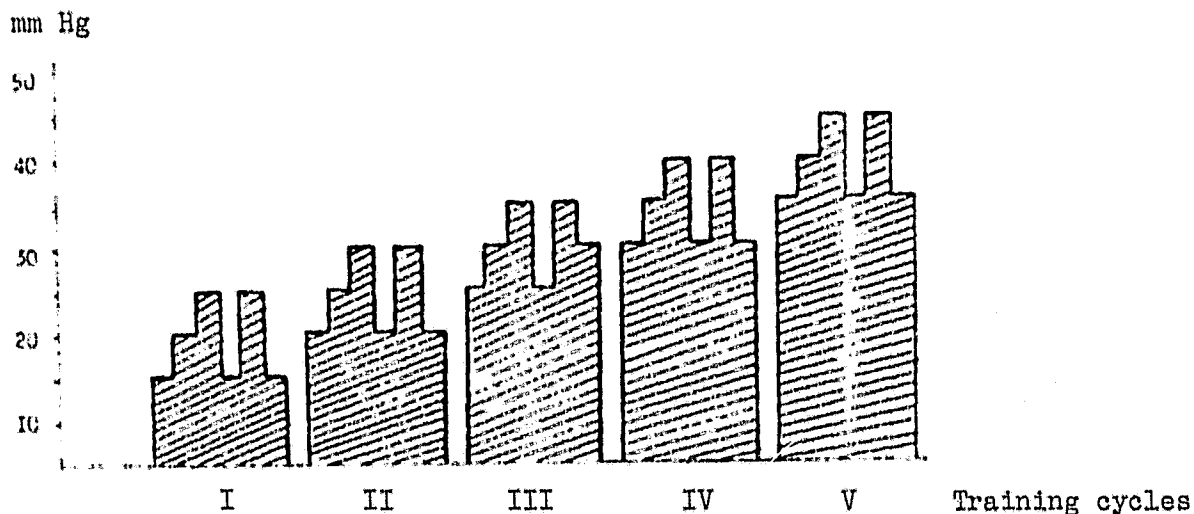


Fig. 7. Diagram of 5 day NLBT training in 14 day study with antiorthostatic hypokinesia.

Six subjects (series 2) followed a similar NLBT training program but including leg movement. Three of them simulated walking in a rhythm of 16-18 steps/min and caused a drop in the vacuum tube of + 10-20 mm Hg compared with the set value. Three of the other subjects likewise simulated "walking" and in addition, at the end of each 5 min cycle of NLBT training flexed and extended their legs to the full and set up a drop in the vacuum tube on the order of 0-60 mm Hg.

TABLE VIII. PRECOLLAPTOID CONDITION DURING ORTHOSTATIC TESTS

Series	Number of subjects	Before ANOH	After ANOH
I	6	-	-
II	6	-	Z-yev, 20 min
III	6	Sh-ov, 15 min	G-ov, 12 min
IV	3	-	
V	3	-	Sh-yets, 19 min
VI	8	-	S-ov, 13 min T-ko, 1 min P-yev, 2 min

Six subjects (series III) trained only for the last 48 hr of ANOH for 120-160 min/day, the mercury column going to 50 mm with fluctuations during leg movement amounting to \pm 10-20 mm Hg.

Three subjects (series IV) were subjected to NLBP training with leg movements daily for 21 min per each mercury reading: 30, 40, 50 mm on even days and 25, 35, 45 mm on odd days, i. e. 63 min/24 hours.

Three (series V) received daily training for an hour at 50 mm Hg using simulated walking combined with a load created by rubber bumpers with the whole arrangement providing a rhythm that caused the pulse /29 rate to reach 120-130/min [22].

Eight subjects (series VI) served as control.

The orthostatic endurance of control group subjects, following termination of 14 day ANOH appeared to be basically lowered, three of them (37.5%) having developed precollaptoid symptoms (Table VIII). Of 24 subjects trained with ANOH only 3 presented a presyncopal state (12.5%).

It should be noted that in connection with all the NLBP training routines we did not observed in a single experimental group a case of complete recovery of retention of orthostatic resistance. It was found that the training program in series I exhibited a positive effect on the subjects' orthostatic stability and proved quite promising. It was also found that the pressure fluctuations in the chamber of the "Chibis" apparatus produced during movements created no unpleasant sensations in the subjects and were not accompanied by negative changes in the physiological indices recorded. Thus, we demonstrated in principle the possibility of combining physical training and NLBP training. In NLBP too leg movement reduced risk of collapse to a minimum (Fig. 8).

"Page missing from available version"

TABLE IX. SCHEME FOR USE OF EPHEDRINE (E) AND STRYCHNINE (S) IN THE STUDIES

Length of ANOH in days	Number of the series	Number of sub-jects	Group	Prepa-ration	Days given and dosage (mg)				
					1-7	8-12	13-14	35-45	46-49
14	I	6	Exper	E S	50 2	80 3	100 3		
	II	3	Exper	E S	35 1	50 1	75 2		
	III	3	Exper	E S	30 1	30 1	50 2		
49	IV	20	Contr						
	V	6	Exper	E S				20 1	40 1

TABLE X. SOME INDICES OF PHYSICAL WORK CAPACITY WITH 49 DAY ANOH IN SIX SUBJECTS GIVEN DRUG PROPHYLAXIS (EXPERIMENTAL) AND SIX CONTROLS (Average data)

Index	Group	Drug	ANOAH (days)					Recup. period (days)	
			12	21	35	49	drug %	1	drug %
PWC ₁₇₀ (kg/min)	Contr	1600	1163	936	909	810	-50.0	650	-59.4
	Exper	1565	1176	1144	1100	1047	-33.1	-	-
Cardiac con- tractions/ 10 min load @ 500 kg/min	Contr	1150	1200	1330	1300	1330	-15.65	1400	+21.8
	Exper	1200	1280	1210	1210	1200	0	1219	+1.5
Cardiac con- tractions/ 10 min rest after load @ 500 kg/min	Contr	770	900	1054	951	1000	+30.0	1268	+64.7
	Exper	769	826	866	908	876	+14.0	868	+12.8

3.4. Pharmacological Preparations

/30

Earlier experiments with animals as well as studies done in cooperation with athletes provided a basic understanding of the effect of a mixture of ephedrine and strychnine given over a long period of treatments as stimulators of physical work capacity in simulation experiments with ANOH (Table IX). In order to get a precise dosage for the preparations under study we conducted 3 series of preliminary experiments with 14 day ANOH. In a 49 day experiment with ANOH administration of the preparations during the last 2 weeks induced no change in the subjects with regard to overall feeling of well being, BP and cardiac contraction rate which were within normal range.

Physical work capacity, determined by the PWC₁₇₀ test, went down during ANOH in 20 control subjects on the average by 15.28 and 45% for days 12, 35 and 49 of ANOH respectively. During the recuperation period physical work capacity was 49 and 20% on days 1 and 1.2 respectively. As an example, Table X presents data for 6 subjects, one from each control group. For them test tolerance went down by 50 and 59% on day 49 of ANOH and day 1 of the recuperation period respectively.

Physical work capacity of subjects in the experimental group went down to a much lesser degree and practically not at all for the period when drugs were administered (days 35 to 49).

Thus it was demonstrated in principle that it is possible to correct physical work capacity and improve functioning of the CVS under ANOH conditions with the use of pharmacological substances.

3.5. Normalization of Food and Salt Regimes

/33

3.5.1. Condition of Water-salt Metabolism with Administration of Sodium Chloride under Conditions of Ordinary Mobility

The research was done with participation of 22 subjects, ages 23-40, who stayed in a hospital under a normal mobility program. The study was conducted in 2 stages: A - search for and selection of the most suitable way to raise the level of organism hydration and resistance to NLBP action; B - assessment of the effect of the program selected in regard to water and salt intake on tolerance to orthostatic effect. Table XI presents the results of the study.

As a result of the study it was established that for all subjects taking part in series III-VI, the ingestion of water, of salt solutions and of water and salt produced a marked rise in the level of organic hydration. However fluid and sodium retention differed in visibility and duration as a function of the regime and makeup by ingredients (Table XII).

After one intake of water (series III) the hydration level went up briefly (by 1.5 in 2 hr), since as the result of water of water load diuresis naturally increased, something very undesirable when this method is used to prevent orthostatic instability in a final spaceflight

TABLE XI. GENERAL CHARACTERISTICS OF STUDIES CARRIED OUT

/34

Study Stage Series	Study conditions	Number of subjects
A I	Background ₁ . Study of initial condition of water-salt metabolism	9
II	Background ₂ . Assessment of initial reaction to NLBP	9
III	Single intake of water: 20 ml/kg body weight	9
IV	Single intake of isotonic NaCl solution (20 ml/kg)	9
V	Fractional intake (equal amounts 8x/48 hr) of isotonic NaCl solution: 3% (a) of wt and 4% (b) of wt	9
VI	Fractional intake (4x equal amounts 0.18 g dry NaCl and 10-12 ml water/kg wt over 10 (a), 14-15 (b) and 20-24 hr (c)	9

B VII	Background ₃ . Study of initial state of water-salt metabolism	9
VIII	Background ₄ . Assessment of initial reaction to orthostasis	12
IX	Fractional intake (4x equal amounts) 0.18 g dry NaCl and 10-12 ml water/kg wt over 20 hr. 30 min before beginning of orthostasis additional 10 ml water/kg wt	12

stage.

Following a single intake of an isotonic NaCl solution (series IV) the high level of hydration was maintained for more than 10 hr. Here there was no substantial change in the amount of diuresis. Despite marked and prolonged water retention, this method likewise did not seem promising, since it induced a number of unwelcome subjective sensations and dyspeptic phenomena. Moreover, some subjects presented a tendency toward bradycardia and higher BP, accompanied in some cases by headache.

Fractional intake of an isotonic NaCl solution (series V) was not marked by the disadvantages noted above. The organism's fluid retention was sharply marked ($P < 0.01$) both after 3-4 hr following the last ingestion of the solution and during a later period, evidence of the potential of taking water and salt. However when a large amount of the salt solution was taken, subjects complained of unpleasant taste sensations.

TABLE XII. DIFFERENCE BETWEEN INTAKE AND KIDNEY EXCRETION OF FLUID (ml) AND SODIUM (mEq) AT DIFFERENT POINTS IN 24 HOURS FOLLOWING INGESTION OF WATER AND NaCl ($\bar{x} \pm S \bar{x}$)

Series	08:00-09:00 (immediately following taking H ₂ O-NaCl additive)		11:00-12:00 (After 3-4 hr)		10:00-18:00 (After 8-10 hr)	
	fluid	NaCl	fluid	NaCl	fluid	NaCl
I	97±39	41±26	176±64	66±30	100±33	74±31
III	1470±66	49±19	360±15	23±8	100±33	100±33
IV	1495±41	233±29	1734±50	27±11	100±33	100±33
V a	576±60	176±37	991±374	277±13	1470±66	49±19
b	1260±304	297±37	1335±304	320±36	100±33	100±33
VI a	486±141	174±41	604±112	235±41	100±33	100±33
b	430±53	135±57	541±303	152±51	100±33	100±33
c	850±34	160±25	832±40	277±43	100±33	100±33

In line with the above it was decided that future research would aim at testing fractional intake of NaCl (0.18 g/kg body wt) in dry form followed by a drink of water. Acceptance of the indicated regime with various modifications (series VI) made it possible to establish that this method provided a high level of hydration for 24 hours and was subjectively assessed as the most comfortable, provoking no side effects whatever. The marked character of fluid retention and salt retention was a function of the manner of employment. The high level of hydration was maintained with greatest stability when subjects were given a water-salt supplement (WSS) at lunch (14:00), dinner (19:00) and before retiring (23:00) as well as breakfast of the next day (8:00) prior to beginning the NLBP studies. With the use of such an arrangement one noticed a practically continuous positive "balance"¹ between fluid and salt (Table XII). The organism would retain about 500-800 ml of fluid and 90-160 mEq of NaCl more than during the same time interval in the absence of such a supplement, which were not excreted for 8-10 hr following ingestion of water and salt (Fig. 9). Additional intake of water, salt solutions or water and salt promoted enhanced resistance on the part of most subjects to the action of NLBP (data of A. A. Savilov).

Thus, the results of the studies carried out showed that the best method for simulation studies under ground conditions is fractional intake of water and dry NaCl for 20 hr until postural action occurs in connection with the ingestion of food (series VI).

"Page missing from available version"

3.5.2. State of Water-salt Metabolism when Salt Solutions are Taken during Longterm Bedrest

Supplemental intake of NaCl and fluid against a background of hypohydration and electrolyte deficit observed in model studies when the subject is kept for a long time under conditions of bedrest or water immersion (BR, WI) may exhibit a different effect on the state of water-salt metabolism and on tolerance towards gravitational action than is noted when the subject has a normal mobility program. To support this thesis we did studies using 12 subjects who, during BR on days 29 and 30, were given a WSS (water-salt supplement) in addition to their aliment ration as indicated in the previous section.

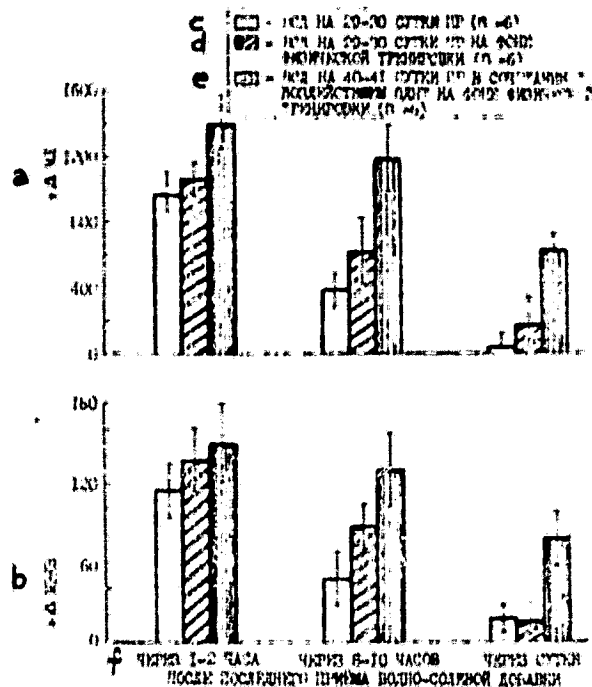


Fig. 10. Difference between intake and kidney excretion of water and NaCl during long BR and taking of WSS including its combination with other prophylactic procedures.

- Key: a. ml b. mEq
 c. WSS on BR days 29-30 (6 subjects)
 d. same on background of physical training (6 subjects)
 e. WSS on BR days 40-41 combined with NLBP on background of physical training (6 subjects)
 f. after 1-2 hr, 8-10 hr, 24 hr following last intake of WSS

It was established that, following intake of WSS, at the moment the orthotest was given fluid retention was on the average 978 ± 126 ml and for NaCl it was 116 ± 9 . The positive "balance" of fluid and salt in the organism was maintained for 5-7 hr following the last taking of the WSS (Fig. 10). Then excretion of sodium, chlorine and diuresis increased and after 8-10 hr (following last taking of WSS) the positive "balance" of these substances was: water only 388 ± 89 and sodium 47 ± 19 mEq. At the end of 24 hr the difference between the water and sodium taken and excreted by the kidneys after the taking of the WSS was not basically different from the values noted during the most proximate 24 hr period of BR free of all effects (Fig. 10). Additional intake of water and salt promoted retention of orthoresistance (V. S. Georgiyevskiy), but the positive effect was shortlived and 8-10 hr later, in the NLBP test, the reaction of the CVS was practically identical with that of subjects receiving no WSS.

Consequently, following intake of WSS under conditions of longterm BR fluid and sodium retention in the organism was less prolonged than for a normal mobile regime. It is clear that in BR the same additional amount of retained fluid is too much for the reduced size, under these conditions, of the vascular bed. If this thesis is

correct, we may anticipate a more marked and more prolonged retention of fluid, sodium and chlorine following intake of a water-salt supplement against a background of physical training or NLBP.

3.5.3. State of Water-salt Metabolism with NLBP during Longterm Bedrest

The study was done using 21 persons kept for 14 and 49 days in antiorthostatic (-4°) hypokinesia (ANOH).

In series I nine subjects, during the last 5 of the 14 days, were subjected to NLBP at pressures from 15-45 mm Hg. The first training day the NLBP lasted 60 min and thereafter 90 min/day. In this series 3 subjects combined NLBP training with physical exercises that simulated walking at 16-18 steps/min. The vacuum container was made to produce pressure variations from zero to 55 mm Hg as a function of NLBP value. Six subjects in the control group (CG) underwent no training whatever during BR.

As a result of the studies it was found that already after day 1 of NLBP most subjects presented lowered diuresis and sodium excretion. On days 2 and 3 of training these changes were most pronounced (Table XIII), when it was noticed that the lower sodium excretion was accompanied by reduced excretion of osmotically active substances. Urea excretion was practically the same as in the control group.

Starting with training day 2 potassium excretion rose and stayed high to the last day of NLBP (Table XIII).

During the NLBP days some subjects exhibited increased water consumption which, together with lowered diuresis, promoted water retention in the organism. It is clear therefore that by the 14th day of BR following 4 days of NLBP training we note an increase ($P < 0.02$) in blood humidity and a decrease ($P < 0.05$) in the amount of osmotically active substances contained in the blood serum and sodium.

In 3 subjects who had simulated walking during NLBP we noted also the same changes as those in the previous group. Probably the slightly lesser excretion of fluid and sodium from the kidneys was the result of their being excreted extrarenally due to high expenditures of energy. Down to the last day of BR the hydration level for these subjects was practically identical with that of subjects who did no leg movements while being trained with NLBP.

In series II three subjects were trained with NLBP for the last 48 hr of BR for 120-157 min at a time and this combined with simulated walking. All subjects presented lower ($P < 0.05$) diuresis, on the average by 395 ± 63 ml/24 hr. Meanwhile water consumption went up and the hydration coefficient (fluid drunk/excreted ratio) rose from 1.09 ± 0.10 on BR day 12 to 1.54 ± 0.12 on BR day 14. Particularly noticeable (from 0.9 to 1.9) was the increase in the value of this index for subject Zh-ov, who prior to NLBP training stood out in regard to low postural endurance. After training his orthostability was better than at the start (based on data of B. S. Katkovskiy). A certain importance in

TABLE XIII. DIURESIS (ml/min) AND EXCRETION RATE OF SODIUM, POTASSIUM (mEq/min), OSMOTICALLY ACTIVE SUBSTANCES ($\mu\text{osm}/\text{min}$) AND UREA (mg/min) DURING BR WITH NLBP IN SUBJECTS OF CONTROL (I) AND EXPERIMENTAL GROUPS (II) ($\bar{x} \pm \bar{x}$)

Research period	Group	Diuresis	Sodium	Potassium	Osmotically active substances	Urea
Bedrest days Before NLBP	I	1,01 \pm 0,06	162 \pm 10	52 \pm 4	741 \pm 37	17,2 \pm 1,9
	II	0,96 \pm 0,05	178 \pm 12	56 \pm 3	788 \pm 72	16,1 \pm 1,2
NLBP	I	1,02 \pm 0,05	179 \pm 13	50 \pm 2	746 \pm 36	17,8 \pm 0,7
	II	0,34 \pm 0,04 ⁺	152 \pm 8	54 \pm 7	705 \pm 53	16,3 \pm 1,7
I0	I	0,96 \pm 0,05	190 \pm 10	57 \pm 5	784 \pm 32	15,1 \pm 0,4
	II	0,72 \pm 0,06 ^x	136 \pm 7 ^x	74 \pm 4 ⁺	693 \pm 30 ^x	16,7 \pm 0,8
I1	I	0,98 \pm 0,04	166 \pm 6	49 \pm 4	766 \pm 71	17,1 \pm 0,4
	II	0,75 \pm 0,04 ^x	131 \pm 8 ^x	65 \pm 5 ⁺	662 \pm 39	15,8 \pm 2,1
I2	I	1,05 \pm 0,03	192 \pm 10	54 \pm 5	841 \pm 57	19,1 \pm 0,8
	II	1,04 \pm 0,07	180 \pm 5	69 \pm 3 ⁺	786 \pm 28	18,0 \pm 0,7
I3	I	1,04 \pm 0,06	178 \pm 5	52 \pm 3	746 \pm 43	15,4 \pm 1,4
	II	0,98 \pm 0,06	157 \pm 7 ⁺	68 \pm 5 ⁺	708 \pm 37	16,5 \pm 1,1
I4	I	0,52 \pm 0,07	108 \pm 5	40 \pm 5	522 \pm 81	13,3 \pm 0,9
	II	0,75 \pm 0,06 ⁺	139 \pm 8 ^x	43 \pm 7	596 \pm 34	12,9 \pm 1,8
Re: very days	I	0,52 \pm 0,07	108 \pm 5	40 \pm 5	522 \pm 81	13,3 \pm 0,9
I	II	0,75 \pm 0,06 ⁺	139 \pm 8 ^x	43 \pm 7	596 \pm 34	12,9 \pm 1,8

+ - $p < 0,05$

x - $p < 0,01$

II in relationship to I during each research period

the improvement of orthoresistance, together with other factors, may be attributed to the substantial rise in the hydration level under the influence of NLBP training.

We noted no significant difference in overall retention of fluid and sodium with the NLBP routines studied, although with 5 day training it was a bit higher. Subjects simulating walking were clearly thirstier.

In a second series of studies 3 subjects during 49 day BR received NLBP training with simulated walking on days 28, 29 and 30 of hypokinesia and during the last 3 BR days. On the NLBP days we noted a drop ($P < 0.05-0.01$) in renal excretion of fluid and sodium. As a result of this the negative fluid-salt balance, noted following longterm BR, was not as pronounced at the time of the orthotest on BR days 30 and 50 as in the control group.

The water load test conducted on day 2 of the recovery period showed reduced excretion of fluid, osmotically active substances and sodium following NLBP training to a lower degree than in the controls. The excretion rate for osmotically free water was likewise higher ($P < 0.05$) following NLBP training.

It is altogether more probable that retention of fluid and sodium during NLBP training the final days of BR resulted in partial buildup of fluid in the organism so that during the first days of the recovery period hypohydration was less pronounced. Therefore, too, compensatory retention of fluid and sodium, both in spontaneous diuresis the first day of the recovery period and in the water test, was less for subjects who had had NLBP.

Thus, as a function of the goals set with the use of various NLBP routines, including its combined application with fluid supplement or a salt solution, it is possible to achieve gradual or rapid elevation of the hydration level for a rather significant period of time whether during normal mobility or during longterm bedrest.

3.5.4. Water-salt Metabolism with Combined Use of Water-salt Supplements with NLBP or Physical Exercises

In the following studies during 49 day BR we came to agreement on a routine for the combination of WSS and training in the "Chibis" apparatus. Twelve persons took part. WSS was taken as in the previous section, while NLBP training was done for 48 hr using a schedule fully described in a special work [22].

It was found that the use of WSS combined with NLBP training on BR days 39-40 promoted a much larger ($P < 0.05$) retention of fluid and sodium than was the case following WSS alone. The greatest difference in values was noted 8-10 days after the last WSS was given, i. e. during the period most significant in respect to application. Subject reaction to orthostasis and the NLBP test was likewise better following combined NLBP training and fractional administration of WSS than after use of NLBP or WSS alone.

These studies led to the conclusion that combined NLBP and WSS is the best way to retain sodium and water during longterm BR and that it promotes enhancement of orthostatic endurance as well as tolerance of the NLBP test over a longer period of time than is the case following the use of each of these methods by themselves.

In view of the fact that in weightlessness there is a deficit of muscular activity and before all an inadequate load placed on the anti-

gravity musculature, on long spaceflights required prophylactic methods will include special types of physical training on the veloergometer, treadmill or special training machines. Therefore all other means for correcting the functional condition of the organism, including those aimed at changes in the water-salt balance and circulatory homeostasis, will best be applied against a background of physical training, which, as is demonstrated above, by itself promotes a certain rise in the level of hydration. Actually, in the case of 6 subjects who during BR did a daily 2 hr of intensive physical exercise (energy expenditure about 300-400 kgm/hr) retention of fluid and sodium following the intake of a WSS was more pronounced and lasting than in subjects who followed a BR hypokinetic program (Fig. 10). However, even here the effect was not as prolonged as that following WSS under conditions of normal motor activity. In view of the fact that use of WSS against a background of physical training and NLBP promoted a more pronounced retention of fluid and sodium, we felt that we should study the effect of their combined use on the condition of the water-salt metabolism in longterm BR.

3.6. The Prophylactic Complex

/47

Testing of each of the above mentioned methods singly and, in a number of cases, in combination, provided a theoretical foundation and practical application of a prophylactic complex agreed upon under conditions of 49 day ANOH.

CYCLOGRAM OF 49 DAY COMPLEX EXPERIMENT - PROPHYLAXIS

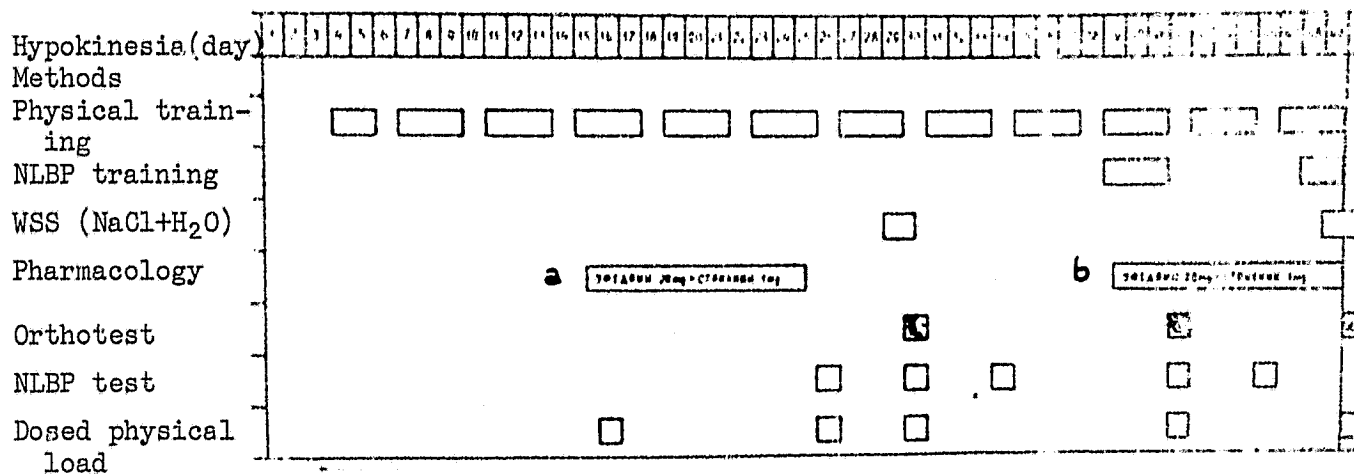


Fig. 11. Outline for administration of second complex experiment with 49 day antiorthostatic hypokinesia (ANOH) (explanation in text).

Key: a. ephedrine 20 mg, strychnine 1 mg b. same

TABLE XIV. PULSE RATE (PR) AND PULSE ARTERIAL PRESSURE (PAP)
FOR SUBJECTS IN VERTICAL POSITION DURING ORTHOTESTS TAKEN
BEFORE BEGINNING AND AFTER END OF 49 DAY ANOH (M±n)

Group	Maximal PR (beats/min)		Maximal PR increase (b/m)		Minimal PAP (mm Hg)		Number of pre- collaptoids	
	Before	After	Before	After	Before	After	Before	After
Control (n=6)	79±3.1	126±4.4	25±3.1	47±6.7	19±2.0	18±1.1	0	3
With phy- sical training (n=6)	106±8.3	114±5.0	32±3.2	44±2.4	18±4.0	24±3.1	0	1
With pro- phylactic complex (n=6)	98±2.1	100±3.1	34±2.2	31±2.8	23±2.1	24±1.6	0	0

As part of the process in a long experiment we did an assessment of various prophylactic combinations. When we had hit upon the most effective, where the effect approximated most closely the condition of subjects at the initial level, we made that complex the basis of a prophylaxis delivery system for the next stage of research. In the research process we systematically made a statistical analysis of the results using T and F criteria and this made it possible to achieve a certain level of reliability ($P < 0.05$) in an objective assessment of effectiveness for each prophylactic complex.

Thus, for example, in the first complex experiment we assessed the possibility of maintaining the initial orthoresistance with the help of a combination of physical training and NLBP.

In view of the fact that in the preliminary 49 day experiment with ANOH it was possible to maintain physical work capacity fully and support to a significant degree the initial condition of the neuromuscular apparatus while orthoresistance appeared reduced, it was decided that in complex experiments physical training would be a constant factor yet supplemented by procedures aimed at restoring orthoresistance.

For this purpose we used 2 day NLBP training in combination with 48 WSS. Convinced of the possibility of restoring orthostability completely through a combination of these procedures, we chose them as basic and obtained further approval for them in the concluding stage of this second complex experiment. Thus, the first one included use of physical training, NLBP and taking of WSS in the final stage of ANOH. The second included the identical procedures plus drugs (Fig. 11).

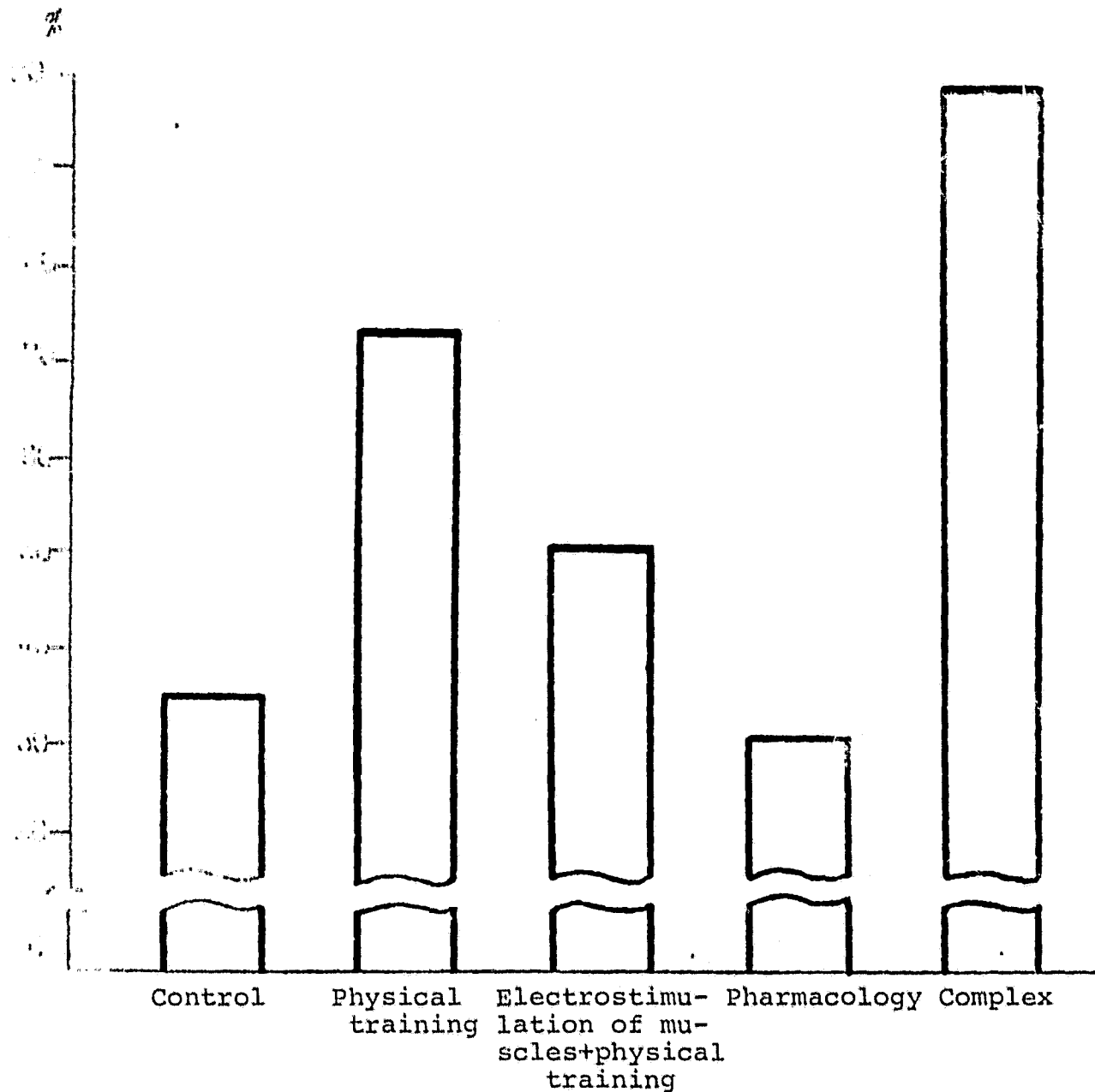


Fig. 12. Change in orthostatic stability following 49 day ANOH with application of various types of prophylactic procedures.

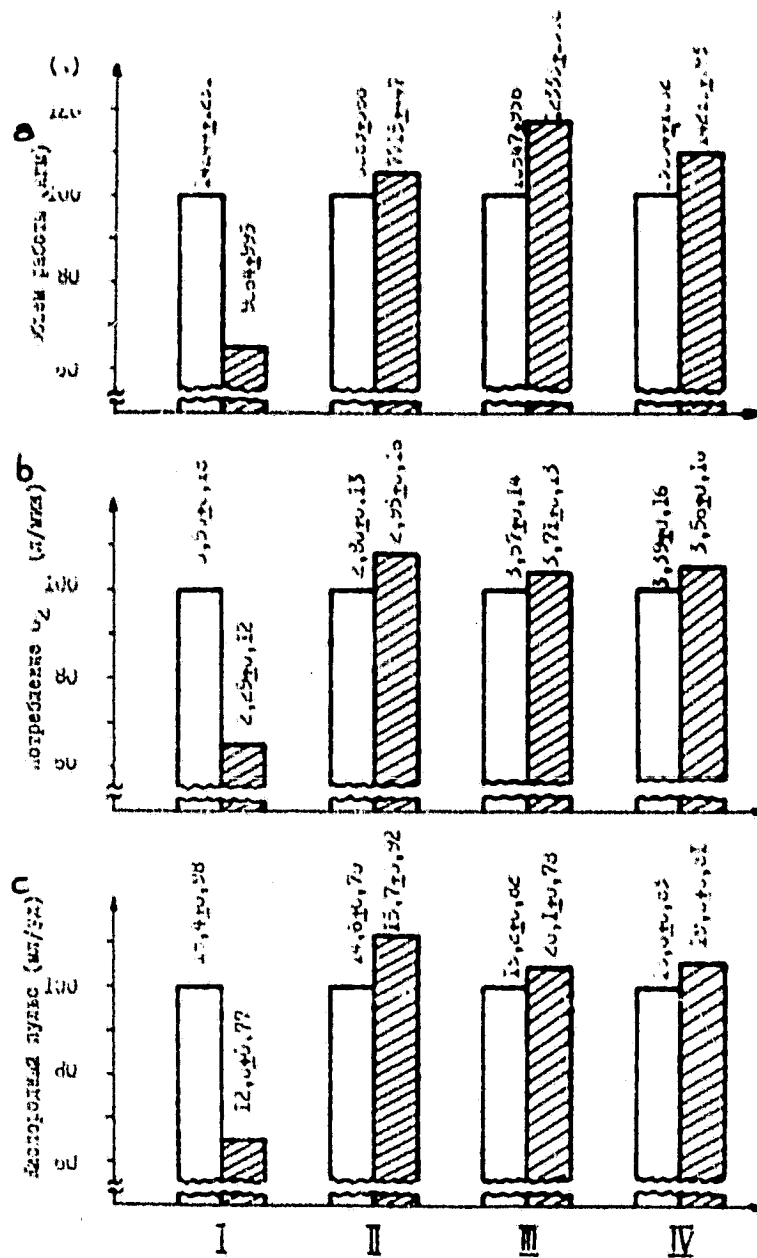


Fig. 13. Some indices of physical work capacity in test subjects before (clear columns) and after (shaded columns) end of 49 day ANOH. Legend: I - control group (n=6), II - physical training group (n=6), III - First complex (n=6), IV - Second complex (n=6).

Key: a. volume of work (kg)
 b. O₂ consumption (l/min)
 c. oxygen pulse (ml/beat)

TABLE XV. QUANTITATIVE ASSESSMENT OF RESULTS (POINTS) OF FUNCTIONAL TESTS TAKEN BEFORE BEGINNING (B) AND AFTER END (A) OF ANOH AND PLACES OCCUPIED BY EXPERIMENTAL GROUPS

Test No.	Summary of exp. conditns. subj.	# of ANOH (days)	Orthostatic test				Maximal physical load				Overall assessment			
			B		A		B		A		B		A	
				%		%		%		%		%		%
1.	Control	12	49	61,6	33,0	-46	70,4	28,2	-60	66,0	30,6	-54	€	
2.	Physical training on KST-2	6	49	60,4	44,8	-26	49,6	56,5	+14	55,0	50,7	-8	;	
3.	PT + myoelectro-stimulation	6	49	60,8	30,0	-51	37,0	46,8	+26	48,9	38,4	-22	;	
4.	First complex	6	49	55,9	58,7	+5	76,4	80,9	+6	66,2	69,8	15	;	
5.	Second complex	6	49	56,7	56,0	-1	76,9	82,8	+8	66,8	69,4	+4	;	
6.	Training on KTF + 5 day NIBP	3 ^{x)}	30	60,7	55,0	-9	69,6	43,8	-37	65,2	49,4	-24	;	

x) experimental conditions and results described earlier [10, 24]

Physical training in the complex experiments was done following a method described in section 3.1. NLBP training was given for 45 min in the "Chibis" apparatus with the mercury column rising steadily from 25 to 60 mm during the last two days of ANOH. Twenty-four hours prior to conclusion of bed rest subjects took a WSS (20 ml water and 0.18 g table salt/kg body wt). 30-40 min before beginning orthostasis along the body's horizontal axis the subject received additional fluid in the amount of 10 ml/kg body wt. Pharmacologically we administered two 10 day courses of ephedrine at a dosage of 20 mg and of strychnine at 1 mg from days 15 to 24 and days 40 to 49 of ANOH. The first and second experimental complexes had 6 participants each. No prophylactic procedures were used on 6 control subjects studied synchronously with the second complex experiment.

Orthostability of subjects in the control group at the end of the 49 day ANOH appeared considerably reduced, while in groups that had had the prophylaxis complex there was no statistical difference from the initial value for a single index recorded. In this respect too they differed from the group where the prophylactic procedure used was physical training alone (Table XIV). Results of the NLBP test are proof that on days 45-47 of ANOH, i. e. up to the time we used procedures aimed at impeding gravitation redistribution of the blood, the reaction of trained subjects was notably worse than at the start even if better than in the control group (Fig. 12).

There was a significant drop in the power of the flexor and extensor muscles following the termination of ANOH for control subjects. Meanwhile, it remained practically the same both for the groups who had had the prophylactic complex and for subjects with the same physical exercises in the preliminary experiment. The same may be said about the results from the study of functional mobility and excitability for the quadriceps femoris: these indices dropped in the control subjects but stayed the same in subjects of the experimental group. The maximum physical load test on the veloergometer indicated that the cardiac contraction rate at which subjects finished work on the veloergometer after 49 day ANOH was scarcely different from values for the control study. The control group showed a reliable drop in the volume of work done, maximal oxygen consumption and oxygen pulse, whereas in groups that had the prophylaxis complex these indices were not statistically different from initial values and showed a tendency to increase (Fig. 13).

4. Conclusion

/51

As everyone knows, both here in the Soviet Union and in the USA a large number of studies have been carried out for the approval of various prophylactic procedures. Nevertheless, when particular routines have been tested in simulation experiments, their preventive effect has proven fairly limited in respect to forestalling the polymorphism of the disturbances involved. This is of course understandable, since it has seemed impossible to find a single procedure that would have a "universal" prophylactic effect. For greater effectiveness there have been proposals of particular combinations of one procedure with another and even various prophylactic complexes. In particular, there has been

produced a theoretical foundation and experimental demonstration of the great effectiveness of physical training combined with NLBP (negative lower body pressure) [4].

In line with the above we attempted to work out more effective prophylactic procedures in respect to the adverse effect of weightlessness, real or simulated. In carrying out this research we solved the most important and tedious problem in the comparative assessment of the effectiveness of different prophylactic procedures as well as some of their combinations on the basis of standardization of an experimental model for weightlessness and unification of evaluation criteria. This had to be done, because in previous research projects different experimental conditions and methods of evaluation had significantly complicated any comparison of the effectiveness of the approved prophylactic procedures.

Our research results justify the following conclusions:

1. Physical training is the most effective prophylactic measure.
2. No single one of the approved procedures and methods of prophylaxis when taken by itself apart from other procedures produced a full prophylactic effect.
3. Special adjustment of regimes, of one prophylactic procedure to another, resulted in enhancement of the prophylactic effect [23].

The application of various prophylactic complexes under conditions of 49 day ANOH (antiorthostatic hypodynamia) resulted in the practical elimination or diminution of the adverse effects of simulated weightlessness and, in particular, retention of orthostatic stability in the subjects, increased physical work capacity and to a great extent forestalling of impairment to metabolic processes in the organism (Table XV).

As worked out, the prophylactic complex made it possible to influence basic changes occurring under conditions of hypokinesia: to a large degree make up for a deficit in muscular activity and align absence of or reduction in the hydrostatic component for blood pressure, restore blood circulation volume and raise the organism's hydration level, which in turn promoted the organism's maintenance of stability in respect to gravity loads.

Thus, the use of a particular prophylactic complex is theoretically justified, while practical approval of its component elements for the orbiting station "Salyut" indicated the significant effectiveness of these components and this is important for medical care in respect to spaceflights.

Footnote

1. We have kept in mind the difference between fluid ingested as part of the liquid component of food and drink and renal excretion.

REFERENCES

1. Genin, A. M. and I. D. Pestov, Eksperimental'noye obosnovaniye razlichnykh metodov preduprezhdeniya vozmozhnykh effektov nevesomosti [Experimental Basis for Various Methods of Preventing the Possible Effects of Weightlessness], Tr. of the IV International Congress "Man in Space", October 1971, Nauka Press, Yerevan, Moscow, 1974, pp 76-90. /55
2. idem, idem, Eksperimental'noye obosnovaniye nekotorykh metodov profilaktiki neblagopriyatnogo deystviya nevesomosti [Experimental Basis for Some Methods of Prophylaxis against the Adverse Effect of Weightlessness], ibid, pp 76-87.
3. Yeremin, A. V., V. V. Bazhanov, V. M. Marishuk et al., Fizicheskaya trenirovka cheloveka v usloviyakh dlitel'noy gipodinamii, v. kn. Problemy kosmicheskoy biologii [Human Physical Training under Conditions of Longterm Hypodynamia, in Problems of Space Biology], Vol. 13, Moscow, 1969, pp 191-199.
4. Genin, A. M. and L. I. Kakurin, 30-sutochniy eksperiment s modelirovaniyem fiziologicheskikh effektov nevesomosti [Thirty Day Experiment in Simulating the Physiological Effects of Weightlessness], Kosmicheskaya biologiya i meditsina 6/4, 26-28 (1972).
5. Stepantsov, V. I., M. A. Tikhonov and A. V. Yeremin, Fizicheskaya trenirovka kak metod profilaktiki gipodinamicheskogo sindroma [Physical Training as a Method for Preventing the Hypodynamic Syndrome], ibid, 64-68.
6. Vasil'yev, P. V., O profilaktike neblagopriyatnogo vliyaniya nevesomosti na organizm cheloveka, v kn. Nevesomost' [Prevention of the Adverse Effect of Weightlessness on the Human Organism, in Weightlessness], Moscow, 1974, pp 278-298.
7. Pestov, I. D., Issledovaniye effektivnosti sredstv i metodov profilaktiki neblagopriyatnykh reaktsiy, svyazannykh s deystviyem nevesomosti na organizm cheloveka [Study of the Effectiveness of Prophylactic Procedures and Methods against Adverse Reactions associated with the Effect of Weightlessness on the Human Organism], Author's abstract of doctoral dissertation, Moscow, 1974.
8. Kakurin, L. I. and V. M. Mikhaylov, Eksperimental'noye obosnovaniye kompleksa profilakticheskikh sredstv dlya dlitel'nykh kosmicheskikh poletov cheloveka [Experimental Basis for a Complex of Prophylactic Procedures in Long Human Spaceflights], Aviakosmicheskaya meditsina, Moscow-Kaluga, 1979, pp 113-115.
9. Pestov, I. D. and B. F. Asyamolov, Otritsatel'noye davleniye na nizhnyuyu chast' tela kak metod profilaktiki sdvigoov svyazannykh s izmeneniyem gidrostaticheskogo davleniya krovi [Negative Pressure on the Lower Part of the Body as a Method of Prophylaxis against Displacements connected with a Change in the Hydrostatic Pressure of the Blood], Kosmicheskaya biologiya i meditsina 6/4, 59-64 (1972). /56

10. Georgiyevskiy, V. S., V. A. Gornago, L. Ya. Divina et al., Ortosticheskaya ustoychivost' v eksperimente s 30-sutochnoy hipokinezey [Orthostatic Stability in an Experiment with 30 Day Hypokinesia], Kosmicheskay biologiya i meditsina 7/6, 61-68 (1973).
11. Suvorov, P. M. and R. V. Beleda, Analiz nekotorykh mekhanizmov ustoychivosti cheloveka k dekompressii nizhney poloviny tela [Analysis of Some Human Stability Mechanisms in respect to Decompression of the Lower Half of the Body], idem 6/6, 56-59 (1972).
12. Balakhovskiy, I. S. and Yu. V. Natochin, Obmen veshchestv v ekstremal'nykh usloviyakh kosmicheskogo poleta i pri ego imitatsii [Metabolism of Substances under Extreme Conditions of Spaceflight, Real or Simulated], Moscow, Kaluga, 1973.
13. Grigor'yev, A. I., Regulyatsiya vodno-elektrolitnogo obmena i funktsii pochek u cheloveka pri kosmicheskikh poletakh [Regulation of Water-electrolyte Metabolism and Human Renal Functions in Spaceflights], Author's abstract of doctoral dissertation, Moscow, 1980.
14. Glod, G. A., V. Ye. Belay, P. V. Vasil'yev et al., Sovmestnoye deystviye stimulyatorov i trankvilizatorov na rabotosposobnost' cheloveka operatora [Simultaneous Effect of Stimulators and Tranquilizers on the Work Capacity of the Human Operator], Kosmich. biol. i med. 6/4, 77-83 (1972).
15. Tishler, V. A., O. D. Anashkin, V. I. Pervushin et al., K voprosu ob intensivnosti nagruzki pri fizicheskoy trenirovke v usloviyakh gipokinezii [The Problem of Intensity of Load in Physical Training under Hypokinetic Conditions], Summary of Addresses at the All-Union Conference on Aviation and Space Medicine, Vol. 2, Moscow-Kaluga, 1975, pp 190-192.
16. Mikhaylov, V. M. and V. S. Georgiyevskiy, Vliyaniye kursa elektrostimulyatsii myshts na ortostaticeskuyu ustoychivost' cheloveka [Effect of a Course of Treatment of Muscles by Electrostimulation on Human Orthostatic Stability], Kosmich. biol. i med. 10/6, 37-41 (1976).
17. Cherepakhin, M. A., L. I. Kakurin, Ye. I. Il'ina and I. L. Fedorenko, Otsenka effektivnosti elektrostimulyatsii myshts v preduprezhdenii rasstroystv, svyazannykh s dlitel'nyim ogranicheniyem dvigatel'noy aktivnosti cheloveka [Assessment of the Effectiveness of Electrostimulation of Muscles in Preventing Disorders connected with Prolonged Restriction of Human Motor Activity], Kosmich. biol. i med. 11/2, 64-68 (1977).

18. Georgiyevskiy, V. S., Ye. A. Il'inskaya, V. I. Matveyev, V. M. Mikhaylov and V. I. Pervushin, Primeneniye elektrostimulyatsii/57 myshts dlya profilaktiki neyromyshechnykh rasstroystv pri 45-sutochnoy antiortostaticheskoy gipokinezii [Use of Muscular Electrostimulation as Prophylaxis against Neuromuscular Disorders in 45 Day Antiorthostatic Hypokinesia], Kosmich. biol. i med. 13/6, 40-43 (1979).
19. Yegorov, B. B., V. S. Georgiyevskiy, V. I. Kiy et al., Znacheniy [sic] elektrostimulyatsii myshts nizhnikh konechnostey v povyshenii ortostaticheskoy ustoychivosti [Significance of electrostimulation of Muscles of the Lower Extremities in Enhancing Orthostatic Stability], ibid 3/6, 62-65 (1969).
20. Balkhovskiy, I. S., V. T. Bakhteyeva, R. V. Beleda et al., Vliyaniye fizicheskoy trenirovki i elektrostimulyatsii na obmen veshchestv [Effect of Physical Training and Electrostimulation on the Metabolism of Substances], ibid 6/4, 68-72 (1972).
21. Gayevskaya, M. S., L. M. Kurkina, S. V. Kolchina et al., Vliyanie fizicheskoy nagruzki i yeye sochetaniya s elektrostimulyatsiyey na normalizatsiyu belkovogo obmena [Effect of Physical Load, Alone and in Combination with Electrostimulation, on Normalization of Protein Metabolism], Summary of an Address at the V International Conference on Aviation and Space Medicine, Kaluga, October 1975.
22. Kakurin, L. I., B. S. Katkovskiy, V. A. Tishler et al., Osnovaniye kompleksa profilakticheskikh sredstv primenitel'no k zadacham poletov orbital'noy stantsii "Salyut" [Basis for a Complex of Prophylactic Procedures as Applied to Problems of Flight on the Orbiting Station "Salyut"], Kosmich. biol. i med. 12/3, 20-27 (1978).
23. Katkovskiy, B. S., G. V. Machinskiy, P. S. Toman et al., Fizicheskaya rabotosposobnost' cheloveka posle 30-sutochnoy gipokinezii s primeneniyyem profilakticheskikh sredstv [Human Physical Work Capacity following 30 Day Hypokinesia with Use of Prophylactic Procedures], ibid 8/4, 43-47 (1974).