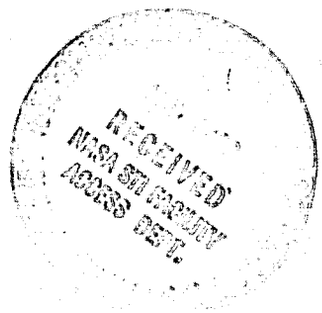
NASA TECHNICAL MEMORANDUM NASA TM-75976

IDEAS OF I. M. SECHENOV IN AVIATION AND SPACE MEDICINE

O. G. Gazenko and Ye. A. Kovalenko

Translation of "Idei I. M. Sechenova v aviatsionnoy i kosmicheskoy meditsine", Priroda, No. 9 (1979), pp 30-37



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 JANUARY 1980

STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-75976		

4. Title and Subtitle	5. Report Date
Ideas of I. M. Sechenov in Aviation and Space Medicine	January 1980
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
O. G. Gazenko and Ye. A. Kovalenko	
	10. Work Unit No.

9. Performing Organization Name and Address	11. Contract or Grant No.
SCITRAN Box 5456 Santa Barbara, CA 93108	NASw-3198
	13. Type of Report and Period Covered
	Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Idei I. M. Sechenova v aviatsionnoy i kosmicheskoy meditsine", Priroda, No. 9 (1979), pp 30-37

16. Abstract

The article's main thrust is the great contribution I. M. Sechenov (19th Century) made to modern physiology. It recalls various of his studies on gases in the blood (O_2 and CO_2), and how these studies where the basic building blocks of current efforts in aviation and space medicine. Schenov also studied hypokinesia, which is becoming important in long duration space flights.

17. Key Words (Selected by Author(s))	18. Distribution Statement
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19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	16	

IDEAS OF I. M. SECHENOV IN AVIATION AND SPACE MEDICINE

by

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/30*

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The beginning of the Russian physiological school by right is linked to the name of I. M. Sechenov. It is enough to recall if but a short list of the works of Ivan Mikhaylovich from the laws of dynamics of blood gasses to the finest mechanisms of the reflex activity of the brain and human

*Numbers in margin indicate pagination in original foreign text.

psychology in order for it to become evident what basic blocks he laid in the foundation of the modern building of physiology.

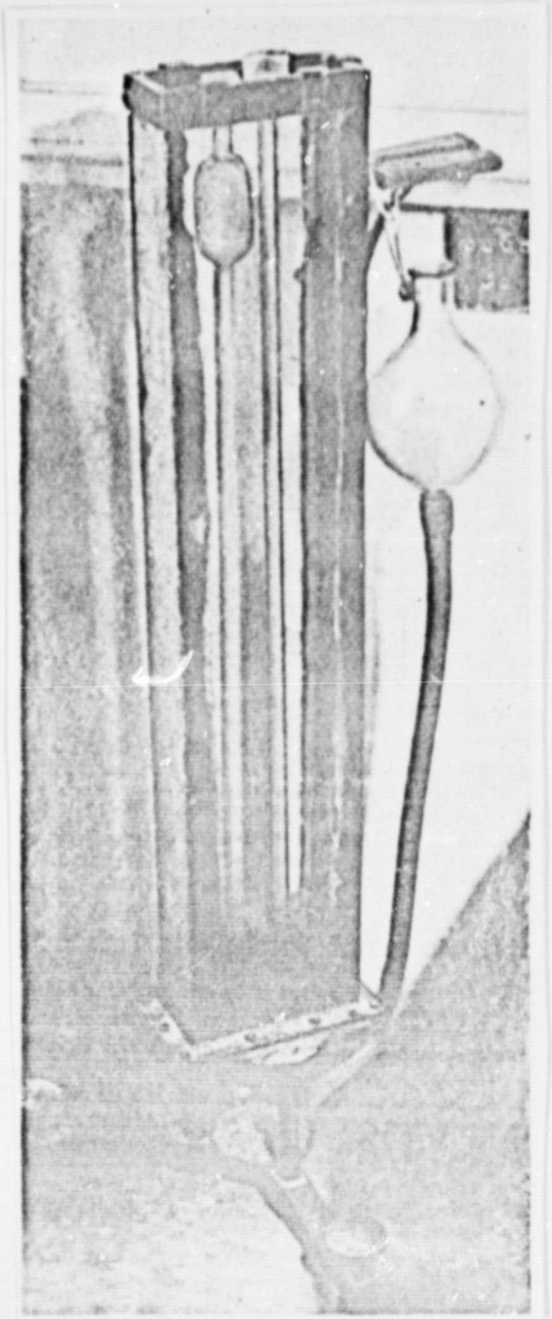
We will turn our attention to one important detail of which Sechenov spoke in his autobiographical notes. Recalling the time of his studies in the Main Military Engineering School (1843-1848) in St. Petersburg Sechenov wrote: "My favorite subject in the senior class was physics; and in proof of the fact that I successfully studied it there is that circumstance that at the public graduating examination that took place in the presence of the head of engineers Geru and many other generals, the teacher of physics selected me to answer on his subject." Further he notes: "In the lower officer's class my love switched to chemistry...I also remember my chemistry exam. Mathematics was easy for me, and I entered the university directly into the physical and mathematical department from the engineering school; thus, I could have become a decent physicist, but fate, as we will see, decided otherwise."[1]

This detail explains well why Sechenov so skilfully used the computations, /31 laws of physics and chemistry in his physiological studies. This clearly shows how important in the training of medical men, biologists or physiologists is a thorough knowledge and love of the exact sciences, of strict logical thinking. In our time this requirement has become especially urgent and is being realized more and more in the system of modern medical and biological education. A knowledge of physics, chemistry and mathematics permitted Sechenov to approach more strictly the study of physiology which at that time almost did not use the arsenal of exact sciences, and at the same time to create a new school of experimental physiology.

The works of Sechenov are directly related to the emergence and development of the most important new directions in physiology and medicine, including aviation and space medicine.

In 1875 in France during the ascent in the balloon "Zenith" to an altitude of 8500 m two of the three aeronauts died. The cause of death of

[1] Sechenov, I. M. Avtobiograficheskiye zapiski ["Autobiographical Notes"] Moscow, 1952, p. 17.



Instrument designed by I. M. Sechenov to determine blood gasses (absorptiometer) which later served as the prototype of many instruments to study the gas composition of blood. The importance of this instrument that opened up new outlooks for the physical-chemical study of the blood was rapidly evaluated by K. Lyudvig who ordered the absorptiometer according to the model of I. M. Sechenov for his laboratory. The instrument is kept in the museum of I. M. Sechenov.

the aeronauts was not clear. Ivan Mikhaylovich took up its solution: "I began to reflect what the aeronauts of "Zenith" could have suffocated from at an altitude of 1/3 of the atmosphere, i.e., I was engaged in the computation of to what measure the influx of O_2 was insufficient for respiration during each respiratory period, based on the physiological data available on this subject."[2] A detailed analysis of this problem in the end led Sechenov to the creation of the theory of constant composition of the alveolar air in the lungs of man on earth and its change during elevation into the air. It was established that normally on earth the partial pressure of oxygen (pO_2) in the alveoli is considerably lower than in the atmosphere, and with a rise in the air it is altered in the alveoli more sharply than in the air of the atmosphere.

[2] Ibid, p. 146.

The extreme "critical" magnitude of oxygen partial pressure in the lungs was equal to 20 mm Hg, with a further reduction in the pressure in the organism the most serious disorders develop that are induced by oxygen shortage (hypoxia).

From here there logically followed the need for protection of man from low barometric pressure and oxygen shortage. /32

For the first time the idea of using a hermetically sealed cabin as a protective resource at a high altitude was advanced by a great friend of Sechenov's--D. I. Mendeleyev (1846). Later this idea was developed by K. E. Tsiolkovskiy (1911) who indicated the need for creating an artificial gas atmosphere in the cabins not only of airplanes, but also space vehicles. But in order to create such chambers it was necessary to have strictly substantiated data on the physiology of respiration and change in gasses in the lungs at great altitudes. The work of Sechenov in the area of the physiology of respiration further served as the basis for the development of precise theoretical prerequisites for studying the effect on man of high-altitude hypoxia and search for methods for protection from it during high-altitude flights into the atmosphere and stratosphere.

The entire range of questions on the physiological role of CO_2 which Sechenov began to develop in the series of famous works: "Carbon Dioxide of the Blood," "Absorption of Carbon Dioxide by Saline Solutions," "Question of Gasses of the Blood," and others also deserves great attention. The data of Sechenov on the change in the partial pressure of CO_2 in the alveoli, the nature and peculiarities of its content in the blood, the transfer of CO_2 by the blood from the tissues to the lungs, and the changes in the acid and base properties of the blood entered the textbooks and were an important stage in the formation of our current ideas on the dynamics of gasses in the body. They are also important for those cases where we are concerned with man's prolonged stay in a closed space and the effect on the organism of high concentrations of CO_2 (hypercapnia). Precisely in the works of Sechenov to a considerable measure are the foundations for the studies that pinpointed the effect on the organism of a

drastically increased CO_2 concentration or decrease in O_2. Back in the 1870's Sechenov hypothesized that the erythrocytes themselves can be the transporter of CO_2. As it turned out later this labile link was due not only to the buffer properties of the hemoglobin, but also the formation of the derivative compound--carbamic acid (NH_2 COOH). Carbon dioxide rapidly and easily bonds with amine groups and already in the carbamic form is transferred into the blood. By this means 20%, and sometimes more of the total quantity of CO_2 transported by the blood is transferred from the tissues into the lungs. The works of Sechenov on carbon dioxide were continued by his talented student B. F. Verigo who discovered the law of the mutual effect of oxygen on the binding by blood and its output of carbon dioxide.

A brilliant synthesis of knowledge of physiology, physics and chemistry permitted Sechenov to make a deep and accurate study of the main parameters of gas dynamics in the organism. He not only made experiments to investigate the actual content of O_2 and CO_2 in the alveoli of the lungs and blood, but also for the first time provided mathematical computations of the gas dynamics in the alveoli, arterial and venous blood. Essentially for the first time he defined two important stages in the cascade of partial pressures of O_2 during the penetration of oxygen from the atmosphere into the body (in the lungs and blood).

Further the classic works of D. Barkroft (1927), Dzh. Kholden and D. Pristli (1937), and D. Van-Slank et al. (1924) confirmed a great deal the experimental computations made by I. M. Sechenov. Works on gas metabolism continued and were fruitfully developed by the domestic pathophysiological and physiological schools of V. V. Pashutin (1881) and M. N. Shaternikov (1904). L. A. Orbeli and his students (V. V. Strel'tsov, 1938; A. P. Apollonov, 1937; M. P. Brestkin, 1952) laid the foundations for the creation of the most varied types of oxygen-respiration apparatus for aviation which made it possible for aviation medicine to contribute to the development of all high altitudes.

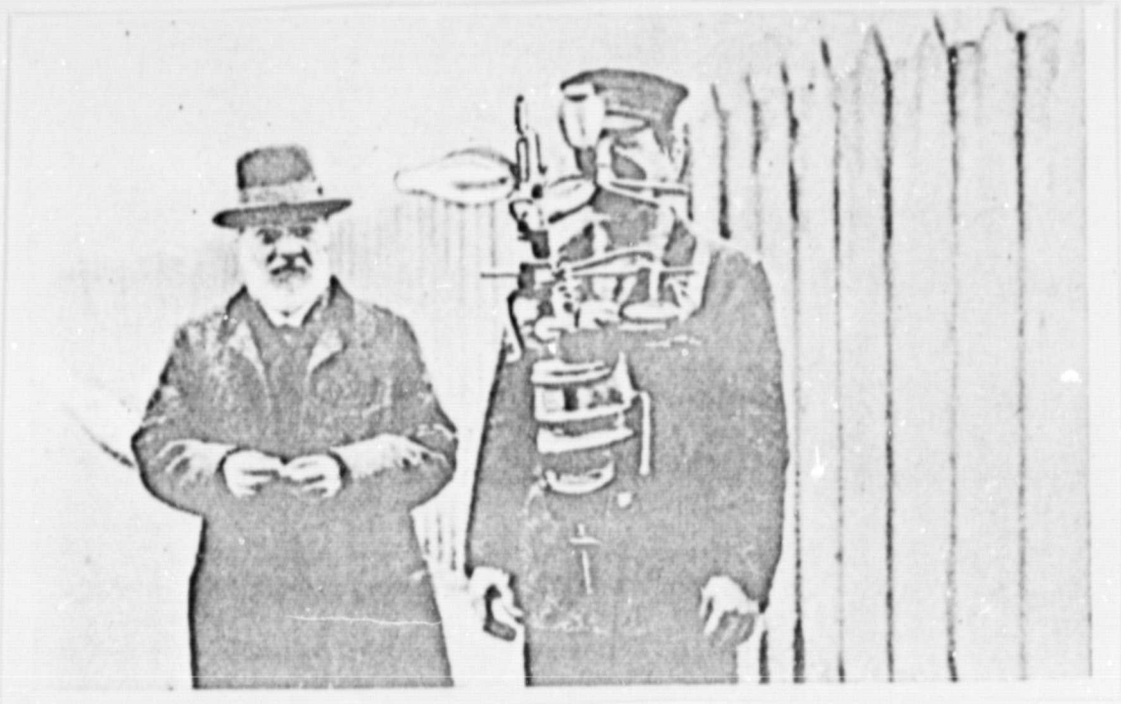
It is necessary to note also the new aspects of this direction. Special attention should be given to the direction on study of blood gasses

started by Ye. M. Kreps (1959), and the introduction by him into the practice of domestic medicine of the new method based on the optic principle for determining oxygenation (saturation with oxygen) of the human blood with the help of an oxygen meter. Precisely such a method and the work carried out in the beginning in the school of Ye. M. Kreps further were very important in aviation medicine for determining the link between oxygenation of blood, bioelectrical activity of the brain, and the overall condition of the organism.

It is natural that these works that have now already become classic were the foundation for ideas on the interaction of oxygen and carbon dioxide in their complex effect on the human organism and animals in different situations. All of these questions are important not only for the practice of terrestrial medicine in anesthesiology, surgery, reanimation, but also for space medicine. This especially concerns the directions linked /33 to the creation and use of ecologically closed systems, with the inclusion in these systems of the plant link or algae.

It is known that for an improvement in photosynthesis it is very advantageous to maintain in the craft atmosphere a somewhat increased concentration of CO_2. This circumstance required from the physiologists a study on the permissible levels for increasing the CO_2 content in the atmosphere of the living compartments of the spacecraft. It was found that the CO_2 content under such conditions can be 10 times greater than the normal.

The new principles for formation of the gas medium of space vehicles are fruitful and promising. The creation of a dynamic artificial gas medium in the atmosphere of the spacecraft with periodic oscillations in it in the levels of pO_2 and pCO_2 for training of the compensatory mechanisms of the organism in weightlessness in its sources is based on the ideas advanced by Sechenov and further developed by his students. In the experiments simulating the physiological effects of weightlessness in combination with prolonged restriction of movements (hypokinesia) it was proven that a change in the composition of the atmosphere (creation of slight hypoxia, and



Portable gas analyzer to study the gas metabolism constructed by I. M. Sechenov jointly with M. N. Shaternikov. The instrument made it possible to study for a long time gas metabolism on a man (at rest and in motion). "I admit frankly that the design of the portable form was a great joy for me, because a study on the move has always been my dream." [Sechenov, I. M. Avtobiograficheskiye zapiski, Moscow, 1945, p. 170]. This instrument whose many glass parts were made by Sechenov himself on a glass-blowing table is now displayed in the museum of I. M. Sechenov. Photograph from the museum of I. M. Sechenov.

sometimes the combination with hypercapnia) trains the organism and promotes and increase in its stability. It was experimentally substantiated by other studies that a moderate oscillation in the composition of the atmosphere in the compartments of the spacecraft can be useful.

A number of ideas advanced for the first time by Sechenov and developed further were the stimulus for the development also of a number of other directions linked to the guarantee of vital activity in underwater craft or the use of hyperbaric therapy, as well as the creation of apparatus for artificial respiration so widespread in surgery. In particular, very /33

interesting data obtained in the clinic of B. V. Petrovskiy indicate the high degree of effectiveness of treating a number of diseases with a significant increase in oxygen pressure. Here it is important to recall that in his time Ivan Mikhaylovich himself for the first time computed the composition of alveolar air with an increase in pressure to 10 atm. and during respiration of pure oxygen.

Thus, essentially, Sechenov noted whole sections of the physiology of respiration that were further developed and received extensive practical application in aviation, astronautics, underwater and clinical medicine.

One can undoubtedly consider a further continuation of the ideas of Sechenov to be the studies on oxygen dynamics directly in different tissues of the body. Precisely in our country in the area of aviation and space medicine for the first time in the 1950-1960's a study was started on the oxygen pattern of the tissues. In experiments on animals a study was made of the peculiarities of pO_2 dynamics in the tissues of the brain and heart under hypoxia, hypercapnia, hypocapnia and hyperoxia. An investigation was made of the oxygen pattern of cerebral tissues during ascents to different altitudes, with simulation of emergency depressurization, under the influence of G-forces, and during the testing of different resources for protection from hypoxia. Further studies were started on the oxygen pattern in the skin tissues of man during simulation of the space flight factors. In these experiments data were successfully obtained on the peculiarities of the oxygen pattern of the body tissues and its changes under the indicated influences.[3]

This trend is being developed in the framework of the "Intercosmos" program in creative cooperation with the scientists of Czechoslovakia, Poland and the GDR. For the first time data were successfully obtained on the peculiarities of the changes in oxygen pressure in the skin tissues directly in a space flight in the cosmonauts V. Remek, A. A. Gubarev, Yu. V. Romanenko, and then in the second international space flight in the

[3] Kovalenko, Ye. A.; and Chernyakov, I. N. "Oxygen of Tissues in Extreme Flight Factors," in Problem Kosmicheskoy Biologii ["Problems of Space Biology"], Moscow, 1972, Vol. 21.

cosmonauts P. I. Klimuk and M. Germashevskiy, and finally, in the third international flight in the cosmonauts V. F. Bykovskiy and Z. Yena. The readers could see the experiment from on board the orbital station "Salyut-6" by television; the experiment received the name "Oxygen" and the cosmonauts determined their own oxygen pressure in the arm tissue.

The works of I. M. Sechenov on the function of nerves and muscle contraction were widely developed in space medicine. Back in 1863 Sechenov convincingly and explicitly expressed the all-embracing value of the function of muscles and movements in human life. "Does a child laugh when it sees a toy, does Garibaldi smile when he was persecuted for excessive love for the motherland, does a girl tremble at the first thought of love, does Newton create world laws and write them on paper--everywhere the definitive fact is muscle movement... All external manifestations of cerebral activity can be reduced to muscular movement."[4] The active, systematic activity of the muscular system on the long path of human evolution always was not only the most important physiological property but also a condition for normal life and development. This situation was sharply altered literally in the last decades. In modern human life man has begun to depend more and more not only on the strength of his muscles, but also on the technical devices he has invented. A new problem has emerged in our century, the problem of hypokinesia, a sharp reduction in muscle activity.

It is known that the artificial conditions of hypokinesia imitate well a number of aspects of the effect of weightlessness on the organism. Therefore hypokinesia has been studied in detail first of all in the framework of space medicine. However terrestrial medicine is beginning to be interested in this problem. The progress of science and technology constantly does a lot to free man to the maximum from heavy muscular work both in modern production and in daily life. Such a trend is understandable and necessary, but it, and more precisely the excessive restriction of the muscular function, hides a serious danger as well. Sechenov warned of this danger: "It is known from the observations on an adult person, on a

[4] Sechenov, I. M. Izbrannyye proizvedeniya ["Selected Works"], Moscow, 1953, Vol. 1, p. 73.

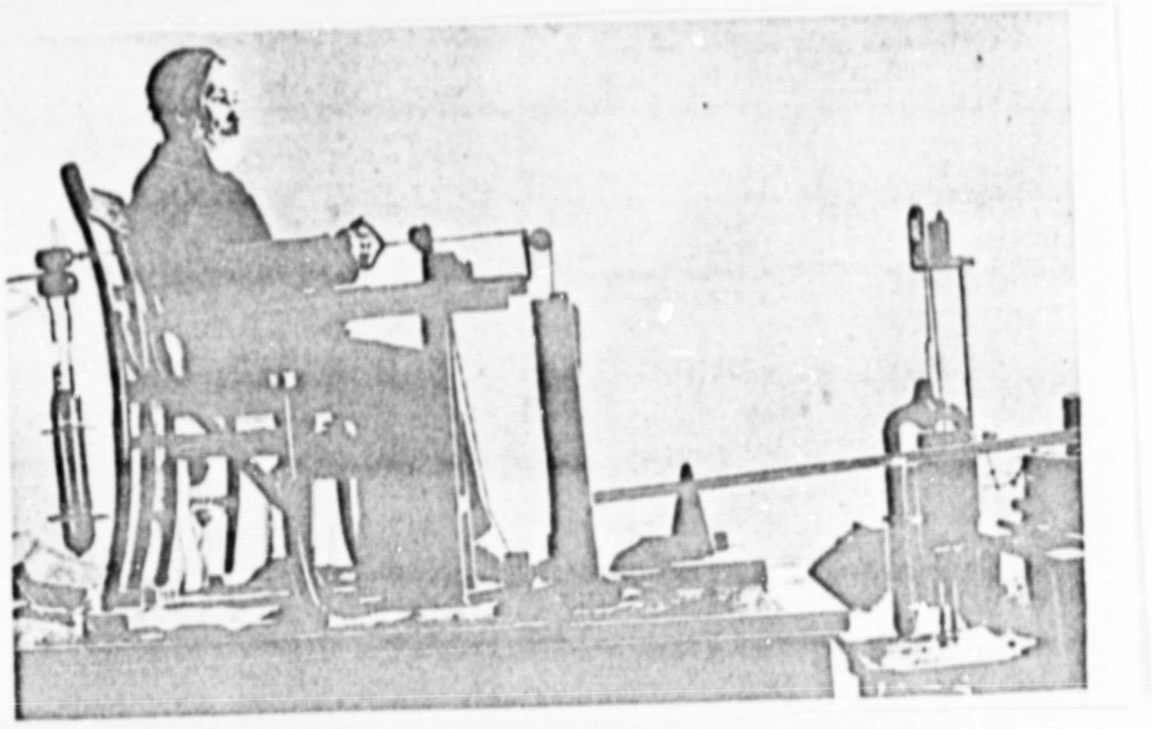
child and on animals that the first condition for maintenance of material integrity, consequently the function of all nerves and muscles without exception is the corresponding exercise of these organs...On the other hand we known that in the case of forced cessation of exercise of any of these organs in man there is a distressing feeling that forces him to look for the lacking exercise."[5] In one of the experiments with the creation of prolonged 120-day artificial hypokinesia in young healthy people important data were obtained. "Clinical observations indicated that already in the first 2-3 days all the subjects complained of pains in different parts of the body, difficulties in falling asleep, headaches, desire to stand up, etc.... Somewhat later, in 4-5 weeks, clearer changes were manifest on the part of the nervous system mainly concerning disruptions in the autonomic sections..."[6] In this same experiment it was noted that from the end of the first month of hypokinesia muscle tone is reduced, progressive atrophy of the muscles occurs, especially crus muscles, and the volume and weight of the muscles is reduced, etc. As we see, the predictions of Sechenov were completely justified. /35

The main idea of Sechenov consisted of the fact that all the muscle acts are the final manifestation of the neural-reflex act. This means that if the final link of these reflex acts is restricted, then primary and fairly serious disorders occur first of all on the part of the reflex acts themselves, and then a number of other more complicated disorders occur in the function of the central nervous system. This most important conclusion that follows from the works of Sechenov was also confirmed in the study of the effect of prolonged 7-day hypokinesia simulating weightlessness in man. /36

In these experiments on healthy young people clear determination was made of the pronounced neurological disorders manifest primarily in the disorders in a number of reflexes, including the tendinous, knee, Achilles' tendon and abdominal. A general hyporeflexia was developed, the muscle

[5] Ibid, p. 226.

[6] Parin, V. V.; Krupin, G. N.; Mikhaylovskiy, G. P.; and Tizul, A. Ya. "Main Changes in the Organism of a Healthy Man during 120-Day Bed Confinement," Kosmicheskaya biologiya i meditsina, No. 5 (1970), p. 59-64.



Two-handled ergograph designed by I. M. Sechenov permitted a study of the rhythm of muscle operation of the arms. Already at age 73 Sechenov again conducted experiments on himself. For several hours he continually made thousands of movements with loads of varying weight. He sought that "most suitable rate of movements of the arms for workers and the greatest load at which the height of its elevation would remain constant for several hours." [Sechenov, I. M. Ocherk rabochikh dvizheniy ["Essay on Workers' Movements"], Moscow, 1901, p. 139]. Based on the experiments I. M. Sechenov came to the conclusion that absolute rest of both arms is not an effective form of rest and restoration of the performance capacity. Only by changing the working muscles can one attain significant results in the struggle against fatigue. This conclusion of I. M. Sechenov was the foundation for the science on "active rest." Photo from the museum of I. M. Sechenov.

strength and tone of the muscles were reduced. Moreover, the changes concerned to a considerable measure the psychological status of the subjects. They noted in their diaries: "Many became completely indifferent, interest lagged, somehow everything faded. There is no special desire to do anything."[7] In the subjects there was a distinct change in the functions of higher nervous activity: sleep was disrupted, often the mood changed, mental performance capacity was sharply reduced and depression reactions appeared,

[7]Panov, A. G.; Lobzin, V. S.; and Belyan, V. A. "Clinical Changes in the Function of the Nervous and Muscle System under the Influence of Prolonged Hypodynamia," in Problemy kosmicheskoy biologii, Moscow, 1969, Vol. 13, pp. 133-147.

irritation, etc. Drastic and prolonged restriction of muscular activity induced multifaceted and significant disorders in the functions, including the central nervous system. In these experiments a sharp reduction was clearly shown in the stability of the body in a vertical position and disorders in the cross coordination of movements; the amplitude of oscillations of the general gravity center of the body was sharply increased as compared to the norm. In other words, the reflex innervation relationships were disrupted that determine the automatic performance of the coordinated activity of muscles even in such normal integral acts as standing, walking, etc. The ideas of Sechenov have both theoretical and important practical importance. They are widely used not only in general physiology, but also in space medicine in the search for and development of the optimal methods for prevention of muscular disorders by means of physical exercises, electrical stimulation of the muscles and certain other methods.

Sechenov for the first time indicated that to restore the functioning of fatigued muscles one can use direct electrical stimulation.[8] This direction today is continuing to be developed by V. N. Chernigovskiy and his school. At the same time especial attention is given not only to the electrical but also to the important value of mechanical stimulations of the receptors under the condition of their natural dynamic change.

In this respect it is necessary to note that an important link in the effect on the organism of weightlessness is precisely the change in the mechanical effect--a unique effect occurs of the removal of microdeformations of the tissues and structures bearing the support function on earth. In weightlessness the effect of microdeformations disappears, consequently a detailed study of this aspect of the problem can permit a clarification of one of the basic aspects in the mechanism for change in afferentation (total designation of excitation going from one or several of the receptors or sense organs to the central nervous system) in weightlessness, as well as an indication of the paths for purposeful influencing of the different receptor terminals. The source of these ideas was also the thoughts expressed by Sechenov.

[8]Sechenov, I. M. Izb. trudy ["Selected Works"], 1935, p. 160.

In our times under conditions of prolonged flights a diverse complex of physical exercises is being successfully employed with the use of veloergometers, "running track," special load-bearing suits and suspenders. Even such lengthy flights on the orbital station "Salyut-6" as flights lasting 96 and 140 days were endured well by the cosmonauts Yu. V. Romanenko and G. M. Grechko, V. V. Kovalenok and A. S. Ivanchenkov. Thus, in this new area of medicine the views of Sechenov on movement as the final link in the reflex act which should be preserved and trained were fruitful in a practical sense.

Apparently, one of the most remarkable aspects of the scientific heritage of Sechenov is the set of his works that covers psychological problems. First of all we note that for space psychology the idea of Sechenov that the mental acts are based on the principle of determinism is extremely important. It is further interesting to note that Sechenov not only separated this principle of approach in analyzing the mental activity, but he approached very close to the modern understanding of physiological mechanisms that guarantee the working tone of the organs of mental activity, the cortex of the large cerebral hemispheres. The conclusion that numerous and diverse afferentation guarantees the working mental activity of the organism belongs precisely to him. The organism needs a constant, diverse stream of afferent stimuli. It always is present in our normal life on earth. 137

Sechenov wrote: "Thus, at the basis for the act of thinking whose content is comparison and observation nothing is revealed except frequent excitations of the sensing tools and the reproduction linked to them of the preceding similar impressions with the motor consequences."[9] Imagine a person who enters weightlessness and completes a very long space flight in the direction of another planet. It is natural that under these conditions in the beginning an explicit change occurs in the excitation of his sense organs. Further as he adapts to the long flight with a drastically reduced stream of diverse external effects customary on earth, or even

[9]Ibid, p. 269.

during flight on orbits close to it an asthenic state can gradually develop. From this situation, essentially, in the general physiological plan predicted by Sechenov modern space psychology draws the practical conclusion and successfully develops a whole set of measures which can remove or significantly attenuate the sensor deprivation (disengagement of external effects) and the general asthenization of the organism. At the same time the set of measures here leaves not only different physical exercises on equipment, but also a number of purely psychological approaches, like for example, looking at interesting films on video magnetophones, listening to music, interesting radio broadcasts, conducting different experiments and working operations, conversations with relatives and friends, etc. At the same time muscle training is constantly carried out. A clear illustration of all that has been said can be the recent flights of the crews on the station "Salyut-6." In these flights for the first time a whole series of new approaches was used that makes it possible to create the optimal "psychological climate" on the craft.

Of great importance for space medicine is the ideas of Sechenov on the perception of space, on spatial memory. This is important in studying the conditions for stay in weightlessness and emergence into open space. For the first time these thoughts were stated in a description of the formation of visual perceptions of the surrounding space and orientation of man in time in the famous work of Sechenov "Reflexes of the Brain."

The ideas of Sechenov subsequently were brilliantly developed in works of I. P. Pavlov and his school, however this question would require a special detailed examination. We find further development of the ideas of Sechenov in the works of different schools of domestic physiologists of our time conducted under the leadership of P. K. Anokhin, P. G. Kostyuk, V. N. Chernigovskiy, Ye. M. Kreps et al. In addition to this the scientific heritage of the father of Russian physiology, as we see, is embodied in the youngest area of biology which is space medicine.