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OF SCIENTIFIC ORGANIZATION OF LABOR
12 AUGUST 1980 BY SERGEY ALEKSANDROVICH KOSILEV 1 OF 2

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Translation

PSYCHOPHYSIOLOGICAL BASES OF SCIENTIFIC ORGANIZATION OF LABOR

By

Sergey Aleksandrovich Kosilev

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PSYCHOPHYSIOLOGICAL BASES OF SCIENTIFIC ORGANIZATION OF LABOR

Complete translation of the Russian-language book by Sergey Aleksandrovich Kosilov: "Psikhofiziologicheskiye osnovy nauchnoy organizatsii truda," published in Moscow by Izdatel'stvo "Ekonomika"

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ANNOTATION

This monograph deals with problems of ensuring optimum participation of the worker in a "man-machine" system and consideration of distinctions of physiological functions and mental processes in organization of labor. The author describes the substance of physiological laws of adjustment to labor, use thereof in designing rational variants of work movements, optimum work and rest schedules, etc. A mathematical interpretation of the dynamics of work fitness makes it possible to make a strictly scientific evaluation of the difficulty and tension of work for specific production sections.

The practical recommendations offered in the book were tested under laboratory and production conditions.

This monograph is intended for workers in NOT [scientific organization of labor] services, students and instructors at VUZ's and faculties of economics.

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INTRODUCTION

The Constitution of the Union of Soviet Socialist Republics states that the government sets as its goal the expansion of existing opportunities for citizens to apply their creativity, capabilities and talents, for comprehensive development of the personality. The state is concerned about improving working conditions and labor safety, scientific organization of labor, reduction of heavy phsyical labor and ultimate complete elimination thereof on the basis of complex mechanization and automation of production processes in all sectors of the national economy.

To provide good working conditions and comprehensive development of the personality, as well as creative capabilities of man, it is imperative to take into consideration the specific laws of adjustment of the human body to work and, on this basis, to elaborate measures that would permit optimization of use of mental and physiological human functions in labor.

The task of industrial psychophysiology is to study the physiological bases of different forms of physical and mental labor, to make comprehensive use of the laws of physiology and psychology in refining work processes.

In ergonomics and engineering psychology, the "man--work tool--object of labor--industrial environment" or "man-machine" system (MMS) is studied as a single functional whole (analogously to the study of other cybernetic systems). Recognition of man's leading role in this system does not detract from the fact that coordination of the features of a human operator with those of machines occurs primarily on the basis of cybernetics, probability theory, mathematical statistics, information theory, queueing theory, network planning, reliability theory, etc. The digression inherent in ergonomics and engineering psychology from complex integration in labor of reflexes that occur on different levels of the nervous system, with the involvement of various functions and various analyzers, results in a simplified equal-component approach to design and analysis of MMS. "... When one designs and analyzes an MMS, man and machine are viewed as separate elements of the system, analysis and description of which are made from the same positions, with the use of the same rating criteria."[1]

The increased attention given to and demands made of working man do not conform with such an equal-component approach, and puts to economists,

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labor and industry organizers the task of studying working man as a complex and independent system governed by specific natural and social laws. Describing the human system from the positions of physiology, I. P. Pavlov indicated that "our system is highly self-regulating, self-supporting, self-restoring, self-repairing and self-improving."[2]

In order to make rational and full use of the reserves for increasing labor productivity, which are to be found in the very nature of man, it is obviously not enough merely to enumerate the operations that a working man must perform and to define the "input" and "output" characteristics of the human element in the man-machine system. It is imperative to investigate the dynamics of functional states of working man and to analyze formation of his work goal and image of necessary work movements, interaction between physiological functions that determine the active forms of his work behavior.

In elaborating measures for scientific organization of labor, comprehensive consideration of physiological and psychological patterns is the most important factor in increasing the efricacy of these measures.

At the present time, the recommendations of industrial psychophysiology are being used with success to solve a number of important national economic problems. In particular, experience with the use of the methods and recommendations of industrial physiology at different enterprises of our country in order to substantiate a rational work schedule and define difficulty of labor was applied to elaboration of universal theory and methods of integral evaluation of fitness for work referable to mental and physical labor[3] and to work out standard intrashift work and rest schedules for industrial workers.[4]

However, the homocentric approach to scientific organization of labor does not amount merely to solving these problems alone. Of first and foremost importance is to deploy scientific research on the psychophysiological capabilities of man in order to disclose the reserves for growth of labor productivity. For this purpose, one should investigate the development of man's work capabilities, physiological processes involved in changing the very nature of working man. According to a well-known thesis of Marxism, "... by exerting his influence on ... the environment and changing it...." working man "... at the same time alters his own nature."[5]

In order to control, purposefully and with scientific substantiation, these changes in human nature, development through work of processes in the body and consciousness of working man, one needs to examine how the skills, work movements, ability to plan one's work, craftsmanship and sophistication of labor are formed through working. Such complex studies of man are pursued by industrial physiology and psychology, which develop in close interaction with one another.

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In this book, we submit the results of contemporary psychophysiological studies of diverse forms of work for the purpose of disclosing the patterns of increased fitness for work and refinement of organization of labor.

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CHAPTER 1. PSYCHOPHYSIOLOGICAL ASPECT OF SCIENTIFIC ORGANIZATION OF LABOR

It is very important to practice a complex scientific approach to solve problems of organization of labor and production. The complex approach permits making the most efficient use of new opportunities, which have appeared with the development of productive forces, science and technology, progressive forms of separation and cooperation of labor. At the 25th Congress of the Communist Party of the Soviet Union, it was stated that it is necessary to "take into comprehensive consideration the requirements of scientific organization of labor in designing new enterprises and remodeling existing ones, and in developing technological processes and equipment."[6]

The complex approach to organization of labor implies that it is necessary to pay serious attention to physiological processes in the human body, to the processes that permit performance of work movements, maintain accuracy and optimum efficiency.

It was noted in the recommendations of the All-Union Conference on Organization of Labor (26-28 June 1967) that "under modern conditions, to be considered scientific organization of labor must be based on scientific advances and progressive knowhow that are being systematically introduced into industry, which permits the optimum combination of equipment and people in a single production process, assures the most efficient use of materials and manpower, continuous increase in labor productivity, aids in preserving human health and gradual transformation of labor into a prime vital need."[7]

It is possible to find effective solutions to problems of scientific organization of labor [NOT] on the basis of the set of engineering, economic, medical and biological sciences. At the present time, it is important to make use of the advances in industrial psychophysiology in research on NOT.

The recommendations of the All-Union Conference on Organization of Labor state that "special attention must be devoted to intensification of scientific research in industrial physiology, psychology and hygiene...."

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"... It is of exceptional importance to elaborate criteria to assess the influence of various industrial factors on the human body, recommendations on rational work and rest schedules, vocational screening and orientation, regulation of labor performed by women and adolescents."[8]

There are a number of distinctions to physiological processes that take place in the human body when working. They are attributable to the fact that they occur in the living human body and they are subject to the influence of social conditions and work goal. By virtue of a work goal, human behavior acquires direction. Man's behavior may not be affected by stimuli outside the work situation, but at the same time stimuli that are neutral outside of his work may become important when he is working. The subordination of man's actions to a work goal leads to distinctive manifestation of more general physical and biochemical processes and laws during work, for example, the law of preserving energy, laws of thermodynamics, etc. While working, physicochemical processes are subordinated by the special laws of work activity, the specific laws of industrial physiology. Industrial physiology, by applying special laws, discloses new avenues for refinement of work and improving man's efficiency.

Efficiency ["fitness for work"] is man's capacity to form and maintain his body in a working state, i.e., to alter the course of physiological functions (functions of the muscular and nervous systems, respiration, circulation, metabolism, etc.) in order to provide for a high level of labor productivity.

Diverse changes and complication of physiological processes take place during formation of the working state. I. P. Pavlov said that many "new processes, new respiration, new heart rate, new secretion, etc.," must begin to perform muscular work. "Time is needed for the new set."[9]

Man solves each specific work problem by means of a special system of reflexes, which is formed in the course of occupational training, renewed and refined in the work process. When work-related reflex systems function they undergo consistent development. This is manifested by complication of structure of the systems and reflection of some elements of these systems in the worker's consciousness. Reflection in consciousness of tangible objects and processes is the content of psychological experiences of man, the basis of logical thinking and accumulation of knowledge, as well as planning of activity. For a tangible process occurring outside the body or within it to be reflected in consciousness, it must have a certain intensity and the body must be sensitive to this process as a nervous system stimulus. It is known that mild physical stimuli delivered to the body surface induce only a local reaction (redness of the skin, change in its temperature, etc.). Stronger stimuli could lead to stimulation of nerve endings which, as it spreads, reaches motor cells and induces a motor reflex, of which man is not yet aware. Upon further increase in intensity of a stimulus, there may be a sensation that is the most elementary form of consciousness.

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Stimuli occurring in the realm of work and industrial relations have a particularly great effect on man. They cause a widely changing range of sensations capable of altering significantly physiological processes; in some cases they are the cause of strong emotions and profound shock of the stress type.

The numerous data obtained by psychologists are indicative of the decisive significance of work in the genesis of mental activity. They confirm the opinion that man's mental processes and traits, ranging from the most elementary ones (for example, sensibility) to the most complex, develop under the influence of his work activity. Work is the main condition of formation of the personality.

Industrial psychology is concerned with changes in mental processes in man's work activity.

In order to provide comprehensive scientific substantiation for organization of labor, it is important to consider the combined occurrence of mental and physiological processes in the worker. The study of relevant theoretical problems and practical tasks from the standpoint of industrial psychology and physiology aids in refinement of organization of labor, since "new opportunities for fruitful research, both general theoretic, basic, and applied, are disclosed on the boundaries between different disciplines."[10]

In this book, the term "psychophysiology" is used in the sense of combination of psychological and physiological factors. I. P. Pavlov wrote: "The natural and inevitable approximation of psychological and physiological elements is occurring and will continue, until finally they will merge."[11] Such a combination occurs in the course of work activity. Moreover, without approximation of work activity proper to formation of a conscious goal, work behavior and creation of use values that would meet public demand would be impossible.

On the basis of research in industry and laboratories, industrial physiologists and psychologists are developing suggestions to refine work and production processes, and they also offer explanations for functional changes occurring during performance of work actions. Industrial physiologists and psychologists apply the appropriate theory and methods to solve practical problems of NOT.

Knowledge of industrial psychophysiology makes it possible to find scientifically substantiated solutions for the problems of organization of labor that are directed toward providing beneficial conditions for the fullest development and use of man's innate abilities, which is the main element of the production system. The most important of these problems are: development, on the basis of physiology of the motor system, of optimum conditions for forming professional work movements, harmonious inclusion in movements of different parts of the body, assimilation of normals of

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the most rational variants of performance of work movements and maintaining the correct work position; design of rational work places and optimum interaction of man and machine on the basis of data on structure and functions of the motor system; specification of requirements made of machines and control thereof, from the standpoint of conformity of the machine with the capabilities of man, as well as development of a rational design of machine control elements, location of levers and control buttons in the worker's field of vision and within the permissible range of movements, etc.; psychophysiological substantiation of advancement of workers' qualifications and effectiveness of industrial training; detection of innate abilities required to acquire work skills, and elaboration of methods for purposeful development of these abilities; provide aid for creative labor of leading workers; development of rational work and rest schedules.

To successfully resolve each of these problems, one must take into consideration a set of factors, the most important one being the factor of psychophysiology of work processes. It is acquiring increasing importance in view of the fact that a modern worker, by virtue of his high professional skill, continuous advanced training, growth of level of general education, not only assimilates the normals of work actions, but finds new and better variants of solutions for production problems, thereby aiding in further development of production.

Comprehension of the goal of a production operation aids in augmenting elements of creativity of workers, as well as their introduction of the latest achievements of scientific and technological progress at the work places. The psychophysiological bases of labor creativity constitute the labor dominant as a socially determined behavioral trend and assimilation of higher paces of work as a result of accumulation in the nervous system of traces of stimulation and reinforcement of new work procedures by the achievement of a useful result.

As we know, a man working in industry is exposed to various environmental factors (noise, vibration, lights, temperature, humidity and velocity of air, different impurities in air, etc.). The presence and intensity of these factors are determined on the basis of data in industrial physiology and hygiene, and steps are being elaborated to eliminate them. A change in dynamics of physiological functions (especially the functions of the central nervous system), demonstrable by the methods of industrial physiology, is the earliest sign of the adverse effect of deleterious environmental factors. This circumstance is very important, in view of the fact that the effect of ameliorative measures depends on the severity of adverse changes in the body. The sooner these steps are taken, the greater their effect.

A consistent change in the functional state of the body and, first of all, the central nervous system is an important distinction of physiological

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processes that take place in the human body during work. Under certain conditions, labor has a beneficial effect on the body: muscular activity strengthens the muscles, mental work develops apprehension.

If organization of labor is not rational, there may be depletion of the nervous system, overfatigue, muscular atrophy, etc. In particular, unrhythmic work, when there are alternate periods of idleness and intensive work, is very detrimental to health and leads to diminished efficiency due to stress.

It is known that efficiency and productivity of labor gradually increase at the beginning of a work shift and reach a maximum in the middle of the first half of the work day. This increase in efficiency related to repetition of work actions is called "getting into the swing" or being warmed up ["getting into the work"]. Repetition of work actions during a 6-8-h shift leads to the opposite effect, diminished efficiency or production fatigue. Numerous repetition of work actions and prolonged work activity elicits different results: getting into the swing or fatigue. If we were to describe the efficiency level as a function of time (hours in the work shift), this function would have a low value at the start of the work cycle (shift, week) and gradually increase; at the end it would gradually decrease and come close to the minimum. Consequently, the function has a maximum value at the middle of the cycle. The conditions under which efficiency reaches and retains a maximum are between the lowest and highest values of the independent variable (time, work load, pace, etc.), i.e., in the range of its optimum values. In order to determine the optimum values of independent variables--working conditions, one has to know the main processes and interdependences in work activity, including psychophysiological processes in the human body during work.

When designing and refining production processes, it is imperative to take into consideration not only the economic results of experiments, but criteria for optimizing working conditions and psychophysiological processes.

In the 1920's and 1930's, efforts were made to solve problems of industrial psychophysiology by direct application of general laws of natural sciences to working man. We have disclosed the invalidity of such attempts in historical surveys of problems of industrial physiology.[12] Concurrently with disclosure of the flaws of these simplistic approaches to the problem of altering the nature of man in labor which was worked on by the founders of materialistic theory, studies were conducted in the laboratories of industrial physiology under our supervision of the physiological bases of work activity in industry, and special specific laws were discovered of socially determined formation of skills in work actions, development of muscular, respiratory and cardiovascular systems, as well as higher forms of conscious work activity.

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The theoretical theses we expounded were discussed at conferences and congresses of physiologists and in the press. Concurrently our recommendations were tested in industry, and there was confirmation of their social and economic effects.[13]

Since the demonstrated patterns had a richer content than general physiological patterns, while the area of their application is limited to man's work activity, there are grounds to consider them as the theoretical basis for an independent direction in industrial physiology and psychophysiology. This direction of research and transformation of work processes enables us to solve a number of concrete problems, which ensue from the theoretical premises of psychology, which strived to learn how "new 'units' are formed in brain systems under the influence of socially historic practice, how new functional systems, new 'functional organs' are formed, thanks to which more and more new constellations appear in the human brain, which does not undergo substantial anatomical change."[14] This direction was instrumental in elaboration of modern philosophical theory of interaction between social and biological elements in the development of man.[15]

This direction includes work on physiological problems of NOT: the dynamic working stereotype (DWS) and integral image of work actions. The DWS is a complex system of reflexes that are formed in the course of industrial training and exercise, which are maintained by achievement of a production result, and it improves as a result of optimum summation of traces of nervous stimulation (S. A. Kosilov, 1953, 1957, 1965). In this system, programming and correction of activity take place on the basis of the integral image of the proper work actions.

I. P. Pavlov maintained that the physiological basis of developing habits is conditioned reflexes. But he warned that it would be a mistake to extrapolate directly to man the general laws of conditioned reflex activity demonstrated in animal experiments.[16] This warning is also very important to the latest theories being expounded by physiologists on the basis of experimentation on animals and studies that are pursued apart from the problems of work activity.

A. R. Luriya, the prominent theoretician of modern psychophysiology, stressed the great importance of physiological theories based on facts obtained beyond the realm of labor and industrial relations to formulation of general theses "on construction of the main units of brain work." However, even he observed that it would be wrong to believe that the "physiology of activity" of N. A. Bernshteyn (1966) and "functional system theory" of P. K. Anokhin (1968) "have already created a finished physiological system that conforms entirely with the main task, that of describing the physiological bases of higher forms of conscious life." Both theories "merely laid the foundation for solving this problem, but by no means solved it. Upon further work on this problem, it must be borne

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in mind that higher forms of social life ... are the product of the most complex sociohistorical processes, the result of social labor, use of tools for communication of people with one another by means of codes of language formed in social history."[17]

The physiological functions under industrial conditions, which have been studied on experimental models, become elements of the DWS and are governed by reflexes in response to social stimuli (reflexes that are at the basis of the work goal and work motivation). In every occupation there are specific work operations, elements of operations, different work actions and movements. None of them alone can begin without special conditioned stimulation. But if the conditioned reflex, upon which a specific work element, action and movement are based, is contained in the integral system of the DWS, the entire work operation can be performed in response to a single initial conditioned stimulus and receive a single reinforcement in the form of a planned production result. Some cortico-motor-visceral reflexes in the stereotype acquire increased intensity and efficiency, while others weaken or are entirely excluded(for example, exclusion of superfluous movements, concentration of attention on a limited group of objects and signals, etc.).

In view of the fact that occupations make diverse demands of a worker, representatives of different occupations develop DWS differing in structure, with different correlations between reflexes and, consequently, with different interaction of body functions. Thus, if a worker has to perform mechanical work, all functions of his body are mobilized to provide energy to muscles, substances rich in energy and oxygen. Here, of decisive significance to successful work, other conditions being equal, are the functions of movement, respiration and circulation. But if, however, a monitor [controller] must discern fine details through vision, all functions of the body are mobilized to implement precise visual perception, for which purpose sensibility and functional lability of the visual analyzer are increased. When a designer searches for solutions to new problems, all of his physiological functions cooperate in a single, most active function, that of developing new time relationships, which are very close to "what psychologists call assocation, whether this is formation of connections of all sorts of actions, impressions or letters, words and thoughts."[18]

The quality of a specific DWS of a specific occupation depends largely on the extent to which energy and influx of the necessary nervous impulses are provided for the most active physiological function, which is closely related to actions that aid in performing the proper production operation. From the standpoint of industrial physiology, these are physiological functions that are subordinated to the DWS of the occupation in question. The most active of these functions is called the key physiological function.

Analysis of the content and structure of specific DWS inherent in different occupations permits development of a psychophysiological classification of occupations and forms of labor, and definition of the key physiological

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function for each of them. Depending on the nature of the key function, measures are developed to refine work processes with due consideration of psychophysiological data.

The complexity of the reflex system of the DWS refers not only to the fact that its structure contains a large number of different reflexes--system components, but that a unique link is established between these components with typical subordination to one another.

We can explain this reciprocal subordination and integration in the historical aspect of development of the human body and personality.

The neonate reacts to stimuli perceived by the body surface and internal organs; his motor system is governed by nervous impulses that arise from receptors of the skin and viscera. These are predominantly visceromotor reflexes. At a later stage of development of the child, there is formation of motor reflexes, which make up the physiological basis of playing and locomotion (crawling, walking, running). Internal processes (respiration, circulation, metabolism) are subordinated to the task of providing energy for the child's body. In this regard, visceromotor reflexes acquire great and even predominant significance. As the child and adolescent become exposed to work activity, motor reflexes are combined into a system of a DWS and are governed by the conscious goal of work, which reflects the instructions of the teacher, educator, example of comrades and fragments of industrial relations. Since the higher branches of the brain are the material substrate of this reflective activity, this type of integration of reflexes can be called corticovisceromotor integration.

During work, integration of psychophysiological processes becomes more complex, more refined and defined, in accordance with advancement of skill and accumulation of professional experience. In particular, processes of adjustment of respiratory and circulatory functions to work may occur before man starts performing motor activity, and this is typical of the prework state, as well as the emotions of a worker which are related to beginning of work.

In view of the complexity of the DWS, studies of its structure and analysis of development, disruption and restoration under changing conditions are performed with the use of models that reproduce the different properties of the DWS. One of these models is a neuromuscular preparation, in which the frog's gastrocnemius, under the influence of electric discharges, contracts and can lift weights, thus performing mechanical work.

The laboratory model of labor used in psychophysiological studies must reflect changes in condition of the nervous system. Work on a digital or manual ergograph, with recording of action currents of muscles and cerebral cortex, is one of the laboratory models that can be used to study changes in functional state of the nervous system. Work at a control console is simulated in laboratories using experimental consoles, which permit

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changing the location and composition of control signals, knobs and buttons and, concurrently, recording physiological processes related to percpetion and processing of information.

As applied to the DWS, the term "dynamism" means that changes in functional state of a system should be studied in relation to time and nature of active factors, which stimulate first of all the nerve endings in sense organs and the motor system and thus are stimuli of the nervous system. Stimuli of a rather high intensity (above the critical, i.e., threshold, level) induce a response (reaction) by excited nerve centers, from which nervous excitatory impulses flow over nerves to muscles and compel the muscles to contract in such a combination that a given purposeful movement is performed. After termination of the reaction in the nervous system (neurons), excitation remains for some time in the form of a slowly receding trace. If the next work action or next reaction of nerve centers (reflex) occur before the trace of excitation from the prior action or prior reflex is equalized, trace excitation and excitation arising because of formation of a new reflex interact, and there is summation of traces of excitation. Functional mobility or lability of nerve centers change as a result of prolonged summation of excitatory traces, at first concentration and then deconcentration of nervous excitation. The lability of nerve centers is measured by the maximum number of stimuli to which nerve centers can respond without distortion of rhythm, as well as by the size of the interval between these stimuli. Concentration of nervous excitation in time is characterized by reduction of the interval within which there is a reaction (for example, muscular tremor); the concentration of nervous excitation in space is manifested by exclusion of superfluous movements.

The integral image of work actions is a system of traces of excitation, on the basis of which work actions are programmed. A work action is directed toward achievement of a specific goal, of which the worker is aware. At the same time, working man forms a conception of the means of reaching this goal, i.e., a plan of work actions. Along with the conscious plan, traces of excitation from prior activity, which are below the level of consciousness, are also important. Together with the traces of excitation, which are at the physiological basis of conceptions, they form an image to which all special actions and their ultimate result are compared. For example, having a visual image of letters, we recognize them when written in different ways. In work processes, along with formation of conceptions and verbal symbols, there is perception of stimuli by different analyzers (mainly visual and motor); the corresponding traces of excitation are associated and make up the integral image of a work action.

In the course of work, not only each work action is checked by comparing the end result to the planned one, but so is each intermediate stage of action, fine elements of work movements, by comparing them to the integral image of work actions. This constant comparison of image to action is

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performed by the feedback principle. Feedback in machines consists of the fact that the controlled object informs the controlling device about its status. The following is observed in interaction between the two main elements of the closed system of the work process, man and machine: man's perception of information (for example, by observing the readings of monitoring and measuring instruments); processing of the obtained information in the central nervous system and decision making; implementation of decision by handling control elements of the machine; perception via feedback channels of information about the altered state of the machine. When driving a car, the driver controls the actuating mechanism (engine); the driver receives information about the changes in speed as a result of this action via feedback at the output of the car, i.e., the speedometer dial in this case. The obtained information is processed by the driver's nervous system and he makes a decision that conforms with the task of maintaining a specific speed. Depending on his decision, the driver exerts different actions on the car engine. Thus, there is a continuous, cyclic movement of information in the closed cybernetic system.

While man performs work actions, the direct route of information in his nervous system starts in motor cells of the central nervous system, and information travels over this route to actuating organs, i.e., muscles; the reverse route is from nerve endings to sense organs, including endings in the motor system (muscles, joints, tendons), to sensory cells of the central nervous system. The neural conductors over which information, in the form of impulses of nervous excitation, passes to sensory cells are called sensory nerves (or afferent, or centripetal nerves). The conductors over which nerve impulses travel from motor centers to muscles are called motor, or efferent, or centrifugal nerves.

While performing work actions, the exact achievement of the planned result is obtained as a result of the fact that, by means of constant comparison of continuous work actions, work movements, to the corresponding elements of the integral image, there is detection of discrepancies between work processes and the program of activity. A flow of impulses of a corrective nature is the reaction to this discrepancy. Thanks to correction, the trajectory, speed, acceleration, force and other elements of work activity are held within the range specified by the program. This activity, which is called regulation, provides for stability and reliability of function of the DWS. Stability is characterized by the degree of random deviations of work (under relatively constant conditions) from the program, variation of parameters of physiological functions about a mean level that is established in accordance with the program. Reliability reflects assured function of the system under the influence of unusual, disruptive factors.

The above concepts, terms and new methodological approaches, which have been introduced into theory and practice of industrial physiology, made it possible to undertake work for systematic solution of the pressing problems of physiological substantiation of NOT, many of which were previously considered insolvable.

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At the present time, the choice and use of various means that transform labor in accordance with industrial conditions and scientific requirements are based on detailed and comprehensive studies of the dynamics of physiological processes during work and changes in physiological condition of the worker.

Any attempt to improve work processes would be incomplete without consideration of changes in physiological processes and physiological state of the body that take place during work (as well as in connection with intervention in its organization). This thesis ensues from the fact that, according to the general definition, labor is a function of the body from the physiological point of view. This circumstance is also indicated by the criticism by Soviet scientists of the efforts of bourgeois rationalizers to overlook physiological processes that develop in connection with labor, and recognition in Soviet economic science of the fact that the efficiency of the process of interaction of man and machine in labor depends on the practical application, not only of data referable to engineering sciences, but laws of economics, organization, physiology, psychology and aesthetics of labor.

Concurrently with development of basic sciences dealing with physiological and psychological processes that occur during performance of work actions, there was development of applied sciences that deal with problems of refining processes and working conditions on the basis of data referable to industrial physiology and psychology, as well as other sciences dealing with man and work processes.

Engineering psychology is involved in normalization of operator work and rational adaptation of complex technology to man's capabilities.

One of the tasks for engineering psychology is to alter machines and industrial technology as to have them conform with the mental properties of man as much as possible. However, this cannot be done solely on the basis of results of psychological studies. In order to study organization of labor and determine the limit of intensification of labor, in addition to psychological data, we also need data of physiology, anthropometry, toxicology, medicine, biology, engineering and other disciplines. In 1957, the Society for the Study of the Human Factor was founded in the United States for the purpose of using all these disciplines to achieve an increase in intensity, productivity, profitability and safety of labor. The work of this society acquired predominantly engineering psychological orientation.

Somewhat earlier (in 1949), the Society of Ergonomists or International Association of Ergonomic Research was founded in European countries (at first in those where the English language is used). The ergonomic direction differs from engineering psychology in that physiological studies are represented to a greater extent in the former. Both directions

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pursue to the same goal, to optimize operating conditions of a system formed by man, by the industrial technology which is subordinated to him and the environment.

In the Soviet Union, firm ties are being established between these branches of science and industrial psychophysiology. They are manifested, first of all, by the speeches of researchers in the field of ergonomics, engineering psychology, industrial aesthetics at conferences dealing with industrial physiology, participation of physiologists and psychologists in conferences on engineering psychology and aesthetics in engineering, as well as in the complex work on amelioration of working conditions and increasing labor productivity performed by representatives of different directions in the system of disciplines dealing with labor. In the Soviet Union, there are some profound and basic grounds for the close, organic interaction between scientific organization of labor and psychophysiology.

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CHAPTER 2. BIOMECHANICAL CONDITIONS OF ORGANIZATION OF LABOR

The Biomechanical Approach to the Study of Work Movements

Observations of performance of work operations by workers with different qualifications reveal that the movements of the better qualified worker differ from those of an unskilled worker not only with regard to results, but structure and nature of performance in time, i.e., their biomechanical features. Biomechanics is the branch of human physiology that deals with the conditions of movements of parts of the body, displacements of the entire body (locomotion), equilibrium and maintenance of a work position. To solve problems of biomechanics, one uses the methods of mathematics and mechanics, data in physiology and anatomy of the motor system, and laws of reflex regulation of motor activity.

Biomechanics and its methods are used in NOT to assess the rationality of work movements and develop standards for them. Labor organizers and industrial training methodologists, who are armed with the specifications and classification of scientifically substantiated standards of work movements, are able to indicate the only correct means of performing a standard work movement in each specific case and for each work operation.

When designing and rationalizing work operations, the problem does not consist of automatically combining elementary work movements into arbitrary combinations determined solely by the desire to reduce the time for performing an operation, but of organic merging thereof into a single system in accordance with the laws of industrial expediency and reflex self-regulation (conditioned reinforcement of the dynamic working stereotype, integral image of work actions, etc.).

Biomechanics expands significantly the opportunities for studying and rationalizing work and organizing labor, as compared to the widely used methods of determining their duration. According to the criterion of duration of work operations, elements and movements, the work processes for the performance of which the least amount of time is required are considered rational.

With all the simplicity and accessibility of this criterion, which was introduced into organization of labor by Taylor, modern scientific organization of labor cannot be satisfied with it alone, without taking into

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consideration such distinctions of work movements as length and complexity of work trajectories, distribution of effort over different segments of the trajectory, use of gravity and inertia, development of excitation in motor nerve centers, etc.

In designing and refining different industrial systems, modern NOT cannot confine itself solely to selection of means of communication between man and machine that occur at random under industrial conditions. A worker who is left to his own resources and encouraged by a raise can find a variant of performance of some work movement that is acceptable for him without thinking too much about whether this is the optimum variant, i.e., the best of possible ones.

For scientific organization of work movements, it is necessary to take into consideration, in addition to the time factor, coordination of the worker's movements according to parameters of length and forms of work trajectories, proper use of muscular force, application of the laws of control of purposeful movements.

When solving biomechanical problems, the researcher uses the methods of mathematics and mechanics, but biomechanics does not become a branch of mathematics or physics. When studying the movements of man, the methods of geometry and mechanics are used under special conditions, which do not exist in other areas of application of these disciplines. When using biomechanics, the labor organizers must bear in mind that, in this case, mathematics and mechanics are applied to the distinctive element of the human body, which is included in the industrial system. While mechanics of solids acquires specific elements in water or air, mechanics of the motor system, which functions for the purpose of acting on the object of labor, constitutes a special technique for solving problems that are limited to the distinctions of relationship between human organs and technological devices in "man-machine" systems. If this thesis is overlooked, it could lead to gross errors and false conclusions. Excessive adherence to the laws of geometry when reducing the distance of work trajectories is an example of such errors.

In addition to numerous examples of increasing labor productivity by shortening work trajectors (shortening the distance of carrying material, tools, etc.), in the history of industrial physiology there are also examples of increasing labor productivity after replacing short trajectories of work movements with longer ones. Thus, G. P. Konradi, A. D. Slonim and V. S. Farfel' (1935) report on rationalization of work movements at a confectionery factory, where the women workers used simple, straight and short movements. When these movements were replaced with longer curvilinear movements, labor productivity increased by about 27%.

M. I. Vinogradov (1966) analyzed two methods of performing operations of spreading adhesive over a large rubber part in assembling galoshes on a

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conveyer. With one of the methods, the woman worker performed several, straight strokes to apply the glue and with the other, one circular movement that covered the entire surface to be treated. Industrial physiologists recommended the second method, which turned out to be more convenient and effective. The advantages of circular movements over linear ones are determined, in the first place, by the shape of the articular surfaces of the extremity (hand), since radial movements with displacement of parts of the body correspond to the structure of the joints; in the second place, this is attributable to the possibility of making smooth changes from one movement to another, and there is no need to make abrupt movements when stopping on the last stage of the operation or to apply increased force to give momentum to the next movement.

These examples confirm the need to take into consideration the distinctions involved in applying the laws of geometry and mechanics to work movements.

Fundamentals of Rationalization of the Working Position

Physiologists consider the working position as a manifestation of operational rest (A. A. Ukhtomskiy, 1951). Operational rest refers to the constancy and stability of position, which are not related to zero activity of the body, but to its readiness for immediate, effective and preplanned action. Since this rules out other forms of activity, operational rest expressed in the working position is a variant of the dominant. In industrial practice, optimum working positions have been evolved for the mass occupations. When designing the positions for new occupations, one must take into consideration the following most important physiological criteria of rationality of working positions: convenience for development of muscular force required for work; convenience of performance of accurate and rapid hand movements; minimal expenditure of energy to hold the position; maximum production result of work movements.

Accurate and effective movements are obtained when the hands are displaced within the hemisphere circumscribed by the arm that is bent half way in the elbow. In "seated" position, this increases the accuracy of work movements, decreases expenditure of energy and prevents the danger of development of such pathological processes as flat feet and varicose veins. When working in seated position, the body should be kept erect, since this provides beneficial conditions for respiration and circulation and relieves passive tissues of the locomotor system, distension of which could become irreversible and cause curvature of the spine.

These criteria of work positions are simple, and they could appear obvious; nevertheless they are often underestimated in practice. In a number of industries machines are used, operation of which requires much static force in the absence of support for the arms (for example, in the shoe industry). Significant static exertion with the body in an uncomfortable position and repeated over a long period of time leads to loss of elasticity of muscle tissue and ultimately to development of muscle pathology.

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Some foreign authors (Lemann, 1953) believe that the straight "sitting" position is wrong, and that it is more correct and natural to "sit" with the trunk and head bent forward. In their opinion, the chair seat should be slightly tilted backward, to prevent slipping forward when leaning back in the chair. There should be no borders on the front side of the seat. The burden of the body weight should be carried by the skin above the tuber of the ischium, since only it can withstand the corresponding pressure. For this reason, there must be no load on the thigh surface near the popliteal fossa. For this purpose, the height of the seat should be such that the anterior part of the thigh barely touches the seat surface with the leg in vertical position. When working sitting down, a slight tilt forward, with negligible kyphotic bending in the lumbar spine, should be considered the normal position. The opinion that there is difficulty of abdominal and thoracic breathing with the body in bent position is not without grounds. Lemann and other physiologists believe that this cannot play a substantial role, in the first place, because of the low intensity of respiration in seated position and, in the second place, because there is an opportunity for deep breathing during breaks.

The studies of Lundervolt (1951) revealed that with the body erect the muscles of the shoulder girdle and back are subject to a large static load, which is demonstrable when recording the bioelectrical action currents of these muscles, which is not observed with the body in a tilted position. The reduced muscle tension in bent position of the body can be attributed to the fact that part of the tension that balances the bent position develops in passive tissues, in particular, in the ligament system of the neck and thoracic spine. Exposure of the ligament system to prolonged mechanical factors could lead to irreversible deformity, for example, to development of round shoulders.

The suggestion to use chairs with adjustable seat tilt merits attention.[19]

When designing the work position, one must take into consideration the fact that it must be instrumental in helping maintain attention, interest and concentration. These psychophysiological features of the worker's personality are based on the existence in the nervous system of foci of heightened activity, the excitation of which increases in response to the effects of incidental, disrupting factors and which preclude (inhibit) any possible reactions that are superfluous at a given time.

Physiological Bases of Optimization of the Work Place

One of the important directions of scientific organization of labor is rational organization of the work place. Optimum organization of the work place can be achieved by different means, depending on technical conditions, degree of mechanization and automation of production processes.

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In the case of manual labor, economy of energy expended by workers, reduction of work trajectories and of muscular exertion are very important. All this can be achieved when the dimensions and location of equipment, instruments [or tools] and objects of work should conform with the dimension and location of different parts of the worker's body. The work zone, in which a worker can pick up the necessary tool or object of labor without bending the trunk and without moving, is determined with this anthropometric approach.

If the work does not involve great muscular exertion, it is recommended that manual labor be performed in "seated" position. Let us recall that better biomechanical conditions for the use of support reaction and most efficient use of muscular force are created when working in "standing" position if a given form of manual labor requires considerable muscular exertion (10-20 kg).

Let us discuss the biomechanical conditions of performing an efficient work movement with horizontal displacement of a tool, when one has to overcome the significant resistance of the material being treated. Filing metal, sawing metal and wood, etc., are examples of such work. The work movement consists of simultaneous flexing of the arm at the shoulder joint and extension at the elbow. The muscular force applied to the tool is directed forward, at an angle of about 30° in relation to the horizontal surface. There is a reaction by the surface being worked on, the force of which is equal in magnitude and opposite in direction, to push the worker back. This force must be damped by the force of the support reaction of the legs.

If a man is in strictly vertical position, the support reaction is directed vertically and cannot equilibrate the force of the reaction of the treated surface. In order to use the force of the support reaction to retain the correct position and efficiently apply muscular force, one should direct the support reaction at an angle of less than 90° from the horizontal plane. The leg can be fixed at an angle of about 60° by using the force of friction of shoes against the surface of the floor. Then, in a region close to the center of the shoulder joint, there will be balancing of the reaction force R directed at an angle of 60° to the horizontal plane, force of gravity of the head and upper part of the trunk P, and force of reaction of treated object T. The problem is to counterbalance the force of the reaction of the treated surface by means of the correctly chosen magnitude and direction of force of support reaction.

One can calculate the force, with which the legs should extend in the knee and hip joints from the specified positions of parts of the body and magnitude of force developed by the working group of muscles. With a 10 kg force of reaction of the treated object, 20 kg weight of the head and upper part of the trunk, the force of muscles that extend the leg should

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constitute about 17 kg. In "seated" position, it is difficult to develop the force of support reaction equal in magnitude and direction to the force required to counterbalance the reaction of the treated object, since the area of support is relatively small (limited to the area between the ischial tuberosities of the pelvic bone) and cannot change in seated position.

Rational arrangement of tools in the work place is an important condition for a proper work position: objects that are handled with the right hand must be to the right of the worker and those picked up with the left hand, to the left. If the work involves development and prolonged maintenance of significant static exertions, the worker gets tired rapidly. To counterbalance static moments of parts of the body with the force of the support reaction, special arm rests and supports are provided in the work place. Determination of moments of force of gravity counterbalanced by statically tensed muscles is made by means of biomechanical analysis of work positions.

Special measuring systems and methods of design developed by somatography are used for spatial arrangement of the work place and all its elements, including all sorts of devices that the worker needs for the work process.

The task of somatography is to provide a foundation for the design and rendition of the human outline in working on a design of a work place, to be used by engineers, designers, planners, researchers, etc. Various methods of simplification and schematization are used in designing work places. For example, the use of flat models of the human figure (with line of vision and maximum angle of vision), executed on the same scale as the general view of the equipment, is recommended.

An optimum work position elicits fatigue when it has to be maintained for a long time. Prolonged and continuous tension of muscle groups is the cause of development of fatigue. In addition, when a position is held unchanged for a long time, it causes changes in circulation and impairs visceral functions. These deleterious factors could become the cause of occupational diseases. A worker who works standing up may develop varicose veins.

Prolonged work in seated position is also tiring, and it could have an adverse effect on health. When working in seated position, the functions of respiratory and circulatory organs are more labored, particular, abdominal circulation. When working constantly in a bent seated position, there could be development of curvature of the spine.

Alternation of seated and standing positions is recommended to prevent the adverse consequences of holding one work position. There should be chairs of the appropriate height at the work places, with a foot rest and back for support of the lumbar and scapular region.

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When designing tables and chairs for working in seated and standing positions, one must adhere to the following rules: the position of the worker in relation to the work plane must remain unchanged when switching from work in standing position to work in seated position, and vice versa; the angle of vision, at which the worker looks at the object of labor must be constant; the position of the elbow should be 4-5 cm above the table surface; the seat should not make it difficult to change from working in seated position to working in standing position, and vice versa (folding seat, chair that moves in and out from under the work plane).

Nomograms have been plotted to conform the height of the work surface with the height of the worker.[20]

Organization of the work place referable to centralized control of equipment is a complex task. The arrangement of signaling instruments, design of dials, intensity of signals, their diversity and designations on a mnemonic diagram[21] are very important to efficient operator work and safety practices. According to the data of A. A. Krylov, the length of a dial affects the readability of monitoring and measuring instruments. If the length of the dial constitutes less than 8-9° in angular units, a horizontal dial is recommended, but if the angular dimensions are greater than 8-9° readings are taken more rapidly and accurately from round dials.[22]

It is recommended to govern oneself by the following theses when designing control panels: the number and length of work trajectories must be reduced to a minimum; the number of control elements and actions performed with them must be minimal; control elements should be located in accordance with their functional importance, the ones that are the most important and most frequently used should be in zones of greatest accessibility; control elements should be arranged with due consideration of the order in which they are used during work; each action on the control console must be performed in one manner (with the exception of back-up emergency actions); the direction of movement of controls should correspond to the direction of the work effect (direction of movement of work element [organ]); the operator's movement should be curved, with smooth transition from one movement to another, preferably in the horizontal plane, which provides more accuracy; when working with both hands, movements must be synchronous and symmetrical.

Typical examples of planning work places are given in the following books: "Physiological Human Factors Determining Arrangement of a Machine Control Station," by O. L. Sidorov, Moscow, 1962; "Manual of Engineering Psychology for Engineers and Designers," by W. Woodson and D. Conover, translated from English, Moscow, Mir, 1968.

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Problems of Optimization and Normalization of Work Movements

Experience in rationalization of labor confirms the need for optimization and normalization of work movements. The American rationalizer [efficiency expert], R. M. Barnes (1946) developed the principles of economy of movements which are listed in Table 1.

Table 1. Principles of Economy of Movements, after R. Barnes* (abbreviated)

Use of physical force	Organization of work place	Proper use of tools and equipment
Simultaneous work with both hands	Tools should be in a specific place	If the work can be done with the legs or machines, the hands must be free
The hands must not be idle (with the exception of breaks)	Tools should be in front of the worker	
Hand movements must be in opposite directions, simultaneous and symmetrical	Containers for finished products should be filled with the use of slanted planes and force of gravity	Two or more tools should be combined Load on fingers should conform with their force
Simplification of movements		
Use of passive force Continuous movement in an arc	Material and tools should be situated in accordance with order of elementary actions (therbligs)	Prompt preparation of tools and materials is important Handles should be designed to provide maximum grasp surface
Ballistic, free movements are better than fixed ones Adherence to rhythmic of movements	Good illumination and good visibility in worker's field of vision Comfortable seat Comfortable height and location of work table	Controls should be arranged with consideration of movements (without changing body position) and maximum mechanical effect

*Barnes, R. M. "Motion and Time Study," New York, 1946.

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The principles of economic movements listed in Table 1 refer to economy of muscular exertion and time as a desirable result of controlling movements. For example, the table mentions problems of simplifying movements, using passive force (gravity, inertia, flexibility, reaction), performance of free movements, etc. However, it does not show the means of solving these problems. Practice has shown that some workers achieve high labor productivity as a result of meeting the conditions listed in Table 1. But this is their individual property, since we do not know how the most important requirements listed in this table are met and, first of all, the means of "using physical force."

Industrial physiology has its own theory and methods of objective description, study and planning of work movements as self-regulating and controllable physiological processes governed by the laws of formation, refinement and maintenance of working motor stereotypes. With this theory and methodology it is possible to make an objective, quantitative evaluation of the quality of coordination of a specific movement, to describe the optimum variant of work movement, which can be considered as the standard, as well as to meet a number of requirements of a work movement, such as smoothness, use of passive force, rhythm, continuity and simplicity of trajectory, on the basis of the more general physiological mechanism of control and self-regulation of muscular activity, concentration of nervous excitation and muscular force.

Cyclographic studies are pursued to refine analysis of work movements. In our studies, motor activity was viewed as a physiological process that develops in the course of exercise [practice]. We had to find a law, on the basis of which we could predict the attainment of the end result by performing this exercise. The law of concentration of muscular force is such a law (S. A. Kosilov, 1938, 1954, 1959, 1965). Concentration of muscular force consists of the fact that, as exercise progresses, performance of most of the work of this movement is concentrated on an increasingly reduced segment of time and space, which corresponds to the concept of adopting a rhythm.

In the parameters of cyclographic studies of movements, concentration of muscular force is manifested by an increase in rate of development and completion of maximums on curves of movements, velocity, acceleration, force and moments (reduction of time and segments of the work trajectory, in which there is complete development of velocity waves and acceleration of determinant points), increased maximums of velocity and accelerations, increased duration of the interval between adjacent phases of movements. With electrophysiological techniques, the concentration of muscular force is manifested by an increase in rate of development and completion of a group of action currents corresponding to development of a single tetanic seizure. Concentration of muscular force is also characterized by more accurate localization in time and over the trajectories of movement of maximums of velocities and accelerations. This more

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accurate afferent correction is, in this case, one of the consequences of assimilating the rhythm and concentrating muscular force, since it is based on an increase in velocities in the receptor part of the reflex cycle.

For further analysis of concentration of muscular force, we must consider in greater detail the correlations between velocities, accelerations and route traveled by the moving points studied. This task is performed on the basis of the law of kinetic energy. It is known that the energy expended to overcome resistance over a certain route (without accelerating) is defined as the product of resistance to movement multiplied by the route traveled. Since moving force (but one that does not elicit acceleration) equals the resistance to be overcome, work T performed by force P, which overcomes without acceleration a certain resistance on the route S, is calculated as the product of multiplying force P by trajectory S (Poncelet, Coriolis, middle of the 19th century). But we also know that work is needed to impart velocity to a body. On the other hand, a moving body (for example, the wind, water) has a certain efficiency. Let us make the following calculation. When force P is exerted on free mass m, force imparts acceleration to the latter:

$$W = \frac{P}{m}$$

By virtue of acceleration the mass acquires a velocity of $V = Wt$ in time t and travels over a route of $W/2\ t^2$. Consequently:

$$PS = \frac{1}{2} Wt^2 \cdot mW = \frac{1}{2} mW^2t^2 = \frac{1}{2} mV^2 \qquad (1)$$

One half of the product of mass multiplied by the square of velocity is called kinetic energy, or living force, of a moving body. The left part of equation (1) the product of multiplying force by the route traveled, is called work power P performed by force over trajectory S. Thus, equation (1) could be read as follows: kinetic energy acquired by a free body when passing over a certain route equals the work performed by the force exerted on free mass over this route.

When a weight is lifted with the arms extended, muscular force is expended, in the first place, to overcome gravity and, in the second place, to generate kinetic energy in moving elements. Total muscular work involved in lifting a weight was determined from the results of numerous experiments at the moment that the center of gravity of the arm reached maximum velocity. Overall work of muscles equals:

$$Ph + \frac{mV^2}{2} + I\frac{\omega^2}{2},$$

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i.e., it equals the sum of the following: work to raise center of gravity Ph, where P is the weight of the arm and weight and h is the height of elevation of the center of gravity above the initial position at the time it reaches maximum velocity; kinetic energy of the arm and weight at the time of achievement of maximum linear velocity. Kinetic energy equals the sum of products of mass of moving elements of the arm and weight multiplied by half the square of velocity of their centers of gravity (kinetic energy in forward motion); magnitude of kinetic energy in rotating motion of elements of the arm and weight in relation to centers of gravity of the elements. The kinetic energy of a solid of revolution includes the kinetic energy of all particles making up the solid. If one of these particles moves at a distance r from the axis of rotation at linear velocity V, the kinetic energy of this particle is $1/2(mV^2)$.

Let us introduce an angular (in radians) velocity $\omega = \frac{V}{r}$ that is the same for all particles, and we shall obtain $\frac{1}{2} mV^2 = \frac{1}{2} m\omega^2 r^2$.

By adding the kinetic energy of all particles, we shall obtain the kinetic energy of the entire solid in its revolving movement:

$$I \frac{\omega^2}{2} = \frac{1}{2} \sum m_i \omega^2 r_i^2,$$

$\sum m_i r_i^2$ is the moment of inertia in kinetic energy which plays the same role in revolving motion as mass does in forward motion. From the standpoint of physics, the moment of inertia is a gage of resistance of a given solid to rotation, just as mass can serve as a gage of resistance of the solid to forces that strive to impart forward motion to it. Thus, with rotating motion, one can indicate angular velocity ω instead of linear velocity V and moment of inertia I instead of mass m in the formula for kinetic energy.

The angular velocity of movement of parts of the body ω (in radians) is calculated in the following manner: Determination is made of angles (in degrees) traversed by elements within a specific time segment (t) from the graphs of forward motions. Then calculation is made of the number of degrees that could be traveled in 1 s if the velocity were constant during a second, i.e., velocity of motion is related to 1 s. The obtained value, expressed in degrees, is multiplied by π and divided by 180.

The moment of inertia of a single element is calculated as follows:

$$I = Mp^2$$

where M is the mass of the entire system, p is the radius or arm of inertia.

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By the definition of Fisher, the radius of inertia of long elements of the human body equals 0.3 l, where l is the length of the element from the proximal to the distal end.

After the square of angular velocities in radians and moments of inertia of elements are determined, half the product of these parameters will constitute the sought kinetic energy of elements in rotating motion.

The sum of kinetic energy of elements of the arm and weight in forward and rotating motion is the entire kinetic energy of the system of the arm and weight at the time that the center of gravity of the system reaches maximum velocity. If, during further elevation of the arm with the weight the velocity of movement diminishes so that elevation of the arm will equal zero at the end of the movement, the accumulated kinetic energy at this time is expended to maintain upward movement. Thus, in the top part of the trajector of lifting the weight, muscular work is alleviated by the fact that kinetic energy is involved in upward motion. The higher the maximum velocity attained by the moving system, the greater the role of kinetic energy. In the segment of the trajectory, in which movement is performed with deceleration, part of the movement of raising the arm is performed at the expense of accumulated kinetic energy. On the basis of data obtained in numerous experiments that we conducted, we determined the share of work performed at the end of arm raising at the expense of kinetic energy. It was established that this share can increase by 20-60% in the course of exercise.

The trajector in its upper part becomes easier for muscles due to increase in maximum velocities and kinetic energy in the course of practicing weight lifting. This is related to development of high velocity at the start of the weight-lifting trajectory and, consequently, to concentration of muscular work on a short segment of trajectory and time. Such a change becomes possible because of the capacity of the receptor and effector part of the reflex cycle of the motor system to increase the corresponding velocities of function and assimilate the new mode of activity. The change in function of the motor system in the course of exercise aids in economy of muscular activity. At the end of the motion of weight lifting, the conditions for muscular contraction become unfavorable for two reasons: because of the increase in moment of force of gravity, and because of reduction in length of functioning muscles. Thus, the use of kinetic energy instead of energy of muscular contract is extremely advantageous in this segment of the trajectory.

An analogous study of biodynamics of movements in specific forms of work revealed that the principle of concentration of muscular force is a consistent pattern in inception of motion during exercise.

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The principle of concentration of power has been confirmed in studies under both laboratory and production conditions. The parameters of concentration of muscular force--duration of development of waves of velocity and acceleration--can be used as quantitative indicators of the degree of perfection of coordination.

When describing coordination of movements, such properties of work movements are mentioned as rational use of passive force (R. Wagner, 1927; K. Vakhkhol'der, 1928; M. I. Vinogradov, 1958), smoothness and rhythmicity of movements. These properties, as well as exclusion of superfluous movements, are derivatives of the main property of movement, the concentration of muscular exertion.

While one observes rather complete and purposeful use of force of inertia, the weight-lifting motion with relief of muscles, which continues with expenditure of kinetic energy, is performed, to a significant extent, under the influence of force of inertia, while lowering the weight is more rational when there is prompt tension of muscles that inhibit the effect of gravity. Prompt muscular contractions are also involved in smoothness of movement. The rhythm of muscular contractions, which is characterized by the proper alternation of periods of activity and relative relaxation of muscles, is also one of the external expressions of concentration of muscular force.

Thus, the study of work movements makes it possible to answer a number of questions that are very important in assessing efficiency and developing measures to improve the work process.

The data pertaining to biomechanics of work movements, which describe the shape and dimensions of work trajectories, can be used to compare the movements under study to standards that were set empirically and found by progressive workers, or developed as a result of planned scientific research. Analysis of the curves of velocities and accelerations developed while performing concrete work movements also helps determine and evaluate accuracy and skill of these movements. The study of movement by the methods of biomechanics makes it possible to provide an objective quantitative description of accuracy, coordination and skill of work movements. Quantitative characteristics refer not only to exogenous mechanical processes, but to the reflex system that implements self-regulation of work movements, i.e., the dynamic work stereotype.

The distribution in time of velocities and accelerations of different parts of the body, development and completion of exertion in different muscle groups in accordance with the existing standards for work movements enable us to evaluate correctly, from the standpoint of physiology, coordination of work movements on the basis of two biomechanical criteria: exclusion of superfluous degrees of freedom and concentration of muscular exertion in the appropriate time interval.

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Standards*of Work Movements

A comprehensive study of different work movements using the above-described methods of biomechanics makes it possible to conclude that movements that aid in more productive labor and which are notable for correct, economical and accurate concentration (high parameters of concentration of muscular force and nervous processes) can be used as standards. The question arises: How should these standards be set? The labor organizer can use the methods described below, depending on how graphic and complete a description is needed to introduce a given standard for a work movement.

Plotting graphs of successive positions is one of the graphic and simple methods of representing the standard for a work movement. For this purpose, successive arm movements (with the tool or object of labor) over specific short (up to 0.1 s) intervals are plotted on millimeter graph paper in a rectangular system of coordinates. On this graph, the elements of the arm are represented in the form of segments of lines limited by the characteristic [determinant] points of the upper limb: the axis of the upper arm is limited by points *b* (center of shoulder joint) and *a* (center of elbow joint); the axis of the forearm is limited by points *a* and *m* (center of radiocarpal joint); the axis of the hand is limited by points *m* and *gm* (center of gravity of the hand).

To plot graphs of successive positions of work movements, one uses the values of coordinates obtained from reading cyclograms and kymocyclograms. From them, one determines the position of the determinant points on the biomechanical diagram of the arm at each moment, at specific intervals of time. Then the points corresponding to a given time are connected by straight lines. Figures 1a and 1b illustrate the graphs of successive positions of normal work movements when cutting metal and sawing a block of wood.

Another method of illustrating standards of work movements is to plot parametric curves expressing coordinates of articulation angles and components of velocity and acceleration of determinant points on the biomechanical diagram of the arm as a function of time (frame number) while performing a given movement. The time in fractions of a second is plotted on the x-axis and the values of the coordinate making up the velocity and accelerations of each determinant points on the biomechanical diagram of the human body are plotted on the y-axis. Figure 2 illustrates examples of parametric curves.

From these curves, one can determine how displacement of each point of the biomechanical diagram develops and should develop with normal movement, in different directions, when one phase ends and another begins (raising, lowering weight and arms, pause in upper or lower position, etc.), how velocity and acceleration develop, when they reach a maximum and to what level these parameters rise.

*Normals

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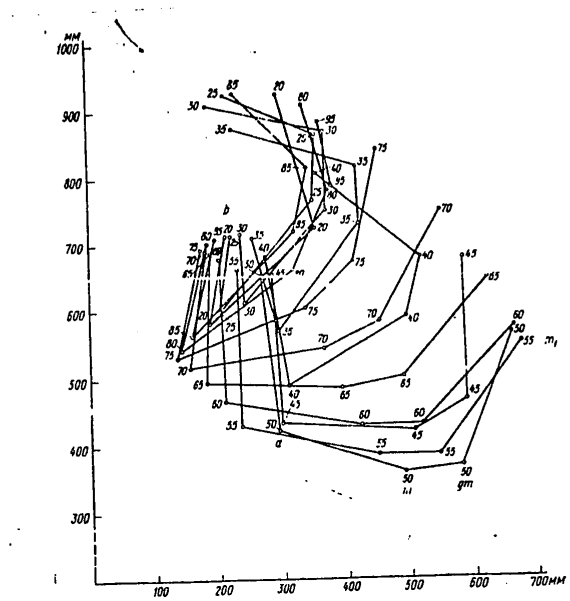

Figure 1a.
Successive positions of axes of arm elements and hammer in hacking metal
a) center of elbow joint
b) center of shoulder joint
m) center of radiocarpal joint
gm) center of gravity of hand
m_1) center of gravity of hammer

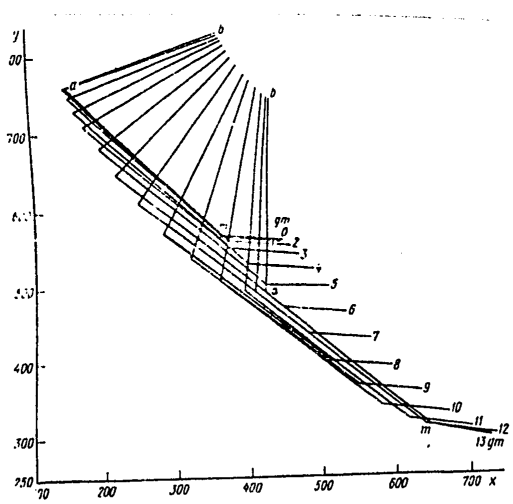

Figure 1b.
Successive positions of axes of arm elements while sawing block of wood

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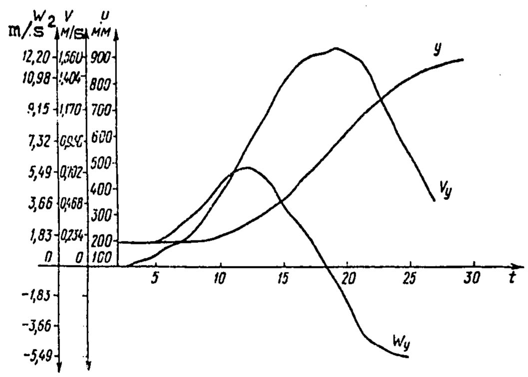

Figure 2. Curves of vertical components of displacement, velocity and acceleration of center of gravity of weight (5.8-kg dumbbell) lifted on extended arm as a function of time (x-axis, time in 40th's of a second; y-axis: y--vertical component of displacement of center of gravity of weight; V_y--velocity component; W_y--acceleration component)

Normal work movements can be analyzed by using tables of the main biomechanical parameters. Data on normal movement in hacking metal can serve as an example of such a description (Table 2).

Table 2 lists information about the vertical and horizontal spread of the hammer's center of gravity, duration of different phases (swinging, hitting, pause), with indication of the presence of an element that is inherent in normal motion when hacking metal, a so-called loop, which is the segment of the working trajectory of the hammer that is formed by motion of the hammer down immediately after hitting the chisel; the values of maximum velocity of the center of gravity of the hammer when swinging and hitting are given, as well as the relation between these values, numerical value of energy of hammer at the moment preceding its contact with the chisel.

In order to simulate work movements, one needs to know the values of angles in arm joints as a function of time. In engineering mechanics, this data are used to build and analyze various devices, as well as to solve problems of control and regulation.[23]

In biomechanical analysis and refinement of work movements, the values of articular angles as a function of time are plotted in the form of curves, with time in fractions of a second on the x-axis and angles of the shoulder (b) and elbow (a) joints on the y-axis (Figure 3). The values of articular angles can be obtained by measuring the angles between the axes of elements of the arm on the curves of successive positions or direct calculation according to the coordinates of determinant [characteristic] points.

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Table 2. Exemplary characteristics of hammer stroke in hacking metal (0.9 kg hammer)

Horizontal swing of hammer, mm	Vertical swing, mm	Duration of motion, s	Mean velocity, m/s	Maximum velocity of blow, m/s	Maximum velocity of swing, m/s	V of blow / V of swing	Kinesthetic energy, kg-m
570-600	400-640	0.74-0.76	1.3	8.6-9.3	2.3-2.9	3.2-3.7	3.4-4.0

Work to raise and drop hammer, kg-m	Work to perform movement as a whole, kg-m	Time of development of swing velocity, s	Time of development of blow velocity, s	Mechanical efficiency, %
1.3-2.0	4.7-6.0	0.32-0.42	0.18-0.23	67-72

Analytical expression of the empirical curves of articulation angles of normal movement enables us to calculate any intermediate value of the angle under study at each given moment of time in seconds, as well as in fractions of the cycle of motion, and it can be considered a mathematical model of normal movement.

Calculation of the relevant formulas is based on the method of expansion of functions in a series, which was developed by Fourier. The complete period of the motor cycle was considered to be 2 π. The values of the angles were expressed as functions of fractions of the period. Work movements that are repeated many times during a shift can be viewed as the sum of harmonics, i.e., sum of functions of the following appearance: $a \cos \omega x + b \sin \omega x + \ldots$, etc., where a and b are constant coefficients, ω is the frequency (number of complete cycles made by a given harmonic motion per unit time) and x is an independent variable. The sinusoidal waves of added harmonics are superimposed over one another, which enables us to plot rather complex curves, which do not have the smooth and symmetrical appearance inherent in sinusoids.

As we know, addition of harmonics is made in such a manner that the arbitrary periodic function is expanded into the sum of harmonics at frequencies of $\omega = 1$, $\omega = 2$, $\omega = 3$, etc. Consequently, the periodic function is represented in the form of an infinite series:

$$f(x) = a_0 + (a_1 \cos x + b_1 \sin x) + (a_2 \cos 2x + b_2 \sin 2x) + \ldots$$

For the function to have the simplest appearance (for example, as shown above),

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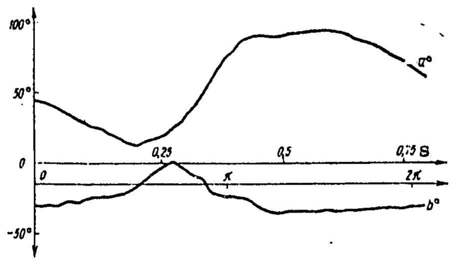

Figure 3. Curves of angles of shoulder (a^0) and elbow (b^0) joints when hacking metal as a function of time; γ = 125 frames/s; x-axis, time in fractions of cycle of movement

Table 3. Approximated formulas of articular angles in work movements as a function of time expressed in fractions of cycle $\left(x = n\frac{\pi}{6}\right)$

		Formulas
Lifting weight on extended arms	Angle of flexion in shoulder joint	$b^\circ = 66{,}5 - 40{,}8\cos x - 4{,}5\cos 2x - 0{,}5\cos 3x$
Free weight-lifting	Angle of flexion in shoulder	$b^\circ = 30 - 34{,}6\cos x + 4{,}3\cos 2x$
	Angle of flexion in elbow	$a^\circ = 174{,}1 + 8{,}3\cos x + 0{,}66\cos 2x - \cos 3x$
	Angle of flexion in shoulder	$b^\circ = 27{,}5 - 6\cos x - 2{,}1\cos 3x + 11{,}3\sin x - 5{,}1\sin 2x + 1{,}8\sin 3x$
Striking motions (when chopping metal)	Angle of flexion in shoulder	$a^\circ = 60{,}8 - 7{,}8\cos x + 4{,}1\cos 2x - 6{,}6\cos 3x - 43{,}3\sin x + 0{,}66\sin 2x - 2{,}6\sin 3x$
Pushing motions (sawing block of wood)	Angle of flexion in shoulder	$b^\circ = -45 - 34\cos x + 5{,}1\cos 2x - 0{,}16\cos 3x$
	Angle of flexion in elbow	$a^\circ = 84{,}4 - 30{,}8\cos x + 5{,}8\cos 2x + 0{,}16\cos 3x$
Forward motion	Angle of flexion in radiocarpal joint	$m^\circ = 147 - 4{,}1\cos x - 0{,}1\cos 2x - 0{,}1\cos 3x$

one must choose the unit of measurement of the independent variable. This will be obtained provided that one full cycle of the function studied develops from beginning to end in the interval from $x = 0$ to $x = 2\pi$. Coefficients a_0, a_1, a_2, etc., are determined by the Euler method. Table 3 lists approximated formulas, which express the values of articular angles in a series of work movements as a function of time expressed in fractions of the period (fractions of π).

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CHAPTER 3. SELF-REGULATION OF PHYSIOLOGICAL PROCESSES IN WORKING MAN

Active Adaptation to Work

In the preceding chapter, we discussed objectively set standards for work positions and movements. These standards were developed on the basis of physiological and biomechanical laws. In setting these standards, the physiological method was used for analysis of specific work positions and movements. The appropriate methods and algorithm make it possible to set new standards of work positions and movements under any industrial conditions where it is necessary to perform new motor actions. A physiologically substantiated method of setting standards of work positions and motions can also be used to design the work movements of robots. In particular, the mathematical formulas that express the values of articular angles as a function of length of motion at a given time in the cycle were used for objective description of the proper and actual movements of artificial elements of the upper extremity (S. A. Kosilov, 1951); formulas expressing muscular force as a function of sample of traction and displacement of points on the biomechanical diagram of man were used to design the mechanism of an artificial arm after amputation of the upper extremity at the shoulder joint (F. S. Vorontsov, 1969).

Rational work places, on which it is planned to perform work actions that are industrially purposeful and physiologically optimal can and must be designed on the basis of the standards for work positions and movements. In the special literature there are examples of rational organization of work places referable to a number of occupations (M. R. Zhuravlev, 1954; O. A. Sidorov, 1962; W. Woodson and D. Conover, 1968, and others).

In most cases, the recommendations on organizing the work place are based on production expediency with due consideration of anthropometric data, and they pertain to only a few typical work processes in modern industry. One cannot demonstrate the diversity of existing work processes on these examples, let alone the means of rational organization of new work places. This is a task that can be successfully performed by industrial physiology, which uses, in addition to the anthropometric approach, the physiological and biomechanical ones, designing new standards of motor actions in accordance with the laws of physiology and biomechanics.

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Thus, industrial physiology is instrumental in implementing rational organization of work positions and movements and, consequently, achieving stable efficiency, both with the existing level of development of technology and with new forms of organization of labor and industry.

The use of standards [normals] of work positions and movements, and of standard work place desings is one of the prerequisites for increasing labor productivity and profitability of industry. However, having the necessary standards for motor activity, the labor and industry organizer can introduce these standards only if the correct means are found for developing in workers the appropriate work skills and abilities.

As shown by the many years of experience in traditional pedagogics, a purely empirical search for these means has not and will not result in finding the optimum method of teaching ability and skills. This method must take into consideration the physiological processes inherent in the human body that aid in adaptation to work activity.

In systems theory, adaptation, or adjustment to changing interaction with new objects, is related to solving the identification problem. In order to study the laws of adaptation of a given controlled cybernetic system, a model of the system is constructed and reactions to a number of input factors are studied. Thus, a study is made of passive adaptation of technical systems designed to simulate, to some extent, some of the functions of a worker. Unlike technical systems, active adaptation is inherent in man, and it has a number of distinctive features, such as the capacity of the nervous system to summate and store traces of excitation that appeared in the nervous system during the work process and, spreading over nerves, led to activation of a muscle. Accumulation in nerve centers of residual, nonspreading excitation alters their functional state, i.e., increases excitability and functional lability, as well as the intensity of excitatory volleys. Concurrent reduction of intervals, during which there is development of separate excitatory volleys, and increased intensity of each volley determine the concentration of muscular exertion in time and, consequently, increased accuracy of movements.

The performance of complex and precise movements is governed by a specific program. In technical systems, the appropriate program is established by a programmer. The worker's work program is formed in the course of summation of traces of excitation in a group of active nerve centers.

The distribution of excitatory traces in the nervous system forms an optimal mosaic or constellation of nerve centers that are notable for heightened activity. The latter becomes the material basis of the functional reflex system of the dynamic work stereotype with an integral image, which is the most important element of the dynamic work stereotype.

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The task for industrial physiology, with respect to substantiation of scientific organization of labor, is not limited to an explanation of how abilities and skills must be acquired; it must include determination of the really existing physiological processes that implement industrial training. All this is needed to elaborate measures in industry and vocational technical schools, directed toward steady development of key (i.e., those important to master an occupation) physiological functions in the trainee.

When searching for the most effective methods of optimum assimilation of vocational abilities and skills, it is very important to take into consideration the distinctions of each young worker who wishes to learn a given occupation. Each individual who has selected a given occupation differs in traits required to work in this occupation.

K. Marx, in an analysis of separation of labor in factories, observed that the most efficient separation of labor is achieved when workers are grouped according to their prevalent capabilities. "Different operations that are performed alternately by a producer and merging into a single whole in the course of his work make different demands of him. In one case, he must develop more force, in another case more skill, in another more attention, etc., but an individual never has these traits to equal extents. After separation, isolating and setting apart different operations, the workers are divided, classified and grouped in accordance with their predominant abilities."[24] Abilities refer to the individual distinctions of a man, which are the subjective prerequisites for successful performance of a specific form of activity. Ability does not reflect some specific material (physiological) process. Psychologists believe that "ability determines what man is capable of doing."[25] Ability is manifested by skill and the results of a specific activity. In the definition of R. Seashore, ability implies a certain hypothetical essence that assures success of a specific activity. Ability does not only determine skill, knowledge and capacity, but itself is based on the influence and mutual determination of inherited traits of the organism, on the one hand, and social living conditions, on the other.

Development of abilities is related to the existence of inclinations in an individual, i.e., specific physiological functions, from which abilities manifested by skill and knowhow under favorable social conditions. Optimum interaction between inclinations and stimuli determined by the influence on the organism of natural and social environment can become the basis for predicting development of knacks and skills required to learn an occupation. Consequently, a certain level of development of appropriate physiological functions, inclinations for abilities, is required to successfully learn a given occupation. The physiological functions, upon which depends the development of skills and knacks that are specific to a given occupation, are the key functions, which permit optimum adaptation to an occupation if they are developed.

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The key functions include functions of the analyzers, analytical and synthetic functions of the nervous system, interaction between signaling systems and reality, as well as functions that constitute the basis of attention, memory, motivation, etc., required for work.

Depending on the level of development of these functions, there is more or less intensive and diverse interaction between man and the social environment, manifested by formation of professional interests, accumulation of knowledge and involvement in social life. According to Marxist theory, "the process of such dialectical interaction of the individual, who has certain inclinations and abilities, with the social environment--other people, products of spiritual culture, public institutions and means of labor--is a process of formation of the personality."[26]

In a socialist society, the pedagogic influences of family and school, participation in work of a team, workshop, institution and public work not only aids in acquiring and advancing the qualifications of a worker, but in his comprehensive development and achievement in work. In order to create favorable conditions for comprehensive development of each worker, one must learn about the structure and functions of the nervous system and psychophysiological processes that occur during work and man's assimilation of vocational abilities and skills. Such information can be found in textbooks of human anatomy and physiology. As one becomes acquainted with such material, one must bear in mind that, unlike animals, people react differently to exogenous stimuli, depending on the experience in social life they have accumulated.

Conditioned reflexes, which are the basis of human work skills, differ substantially from the conditioned reflexes of animals. Conditioned reflexes of man are complex systems of reflexes of the first and second signaling systems in response to stimuli from the social environment, to which man has developed a special reaction. It is not the unconditioned reflex that serves as reinforcement of the reflex system of the dynamic work stereotype inresponse to such factors as presentation of food or rejected substance, but achievement of a conscious work goal.

Functional Self-Regulating Systems of Work Behavior

The main physiological mechanism of controlling vital functions of man, the reflex, can be manifested in different forms, depending on the complexity and distinctions of physiological and mental processes involved in work activity. Let us consider some examples of reflexes.

The simplest reflex is the patellar reflex. If one strikes with a mallet the tendon of the femoral quadriceps, this muscle extends, which leads to stimulation of receptors. Excitation passes from receptors to a sensory cell, then to motor cells of the spinal cord and from them to the muscle that extends the leg at the knee.

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The route of excitation is the reflex cycle of the patellar reflex. Many motor reflexes have reflex cycles consisting of many neurons, since intermediate (intercalary) neurons are contained between sensory and effector neurons. In the patellar reflex, excitation passes from a sensory neuron to an effector neuron within the same segment of the spinal cord (without involving segments of the cord that are higher and lower). As a rule, excitation reaches different segments of the spinal cord and different branches of the central nervous system through intercalary neurons.

The patellar reflex is associated with relaxation of antagonist muscles (muscles with the opposite action) and change in muscular tension of the other leg. Each motor act corresponds to a reaction of the cardiovascular and respiratory systems.

The flow of neural impulses from the actual receptors of contracting muscles to the central nervous system elicits a reaction in the nerve centers, which aids in stopping leg movement after completion of the reflex.

Simple defense reflexes occur in a similar manner, for example, pulling the hand away from a pin prick or upon touching a hot object, etc.

Reflexes directed toward regulation of physiological processes are more complex than the patellar and defense reflexes and have more marked feedback. The pupillary reflex, where the pupils constrict in bright light and thereby prevent damage to sensory nerve endings by the bright light and dilate in poor light to increase the force of the stimulus to the retina, is an example of such reflexes. This reflex takes place in the following manner.

Excitation that appears in retinal cells (in rods and cones) under the influence of light spreads over the fibers of a sensory nerve and reaches nerve centers in the anterior part of the brain stem, then it is transmitted to efferent cells, from which impulses travel to muscles of the iris, which regulate the degree of dilation of the pupil in accordance with a specific, optimum light flux. Thus, in the pupillary reflex, as in any machine, information about a certain physical parameter (intensity of illumination) serves to control the motor mechanism that regulates this parameter, bringing it to a specific, close to optimal value.

Another example of regulation is heat regulation. It is known that excessive heat, which accumulates as a result of biochemical processes in the human body and become stronger during intensive physical work, is eliminated by means of evaporation of perspiration and increased heat transfer from the body surface upon dilatation of blood vessels in the skin. The center of heat transfer is in the hypothalamus, which is in the anterior part of the brain stem. A change in temperature of blood passing through the hypothalamus induces dilatation of skin vessels and

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increases perspiration. Thus, a constant skin temperature of 37°C is maintained.

In all of the examples of functional reflex systems discussed, there is regulation (with the use of direct association and feedback) of different functions in order to keep the constant parameters set by nature. Such regulation leads us to assume that there is a special apparatus in the central nervous system that evaluates information from the periphery (about intensity of light flux, body temperature, smoothness of movements, adequacy of pulmonary ventilation, etc.) and determines the magnitude of necessary adjustment of regulated functions. This apparatus is called the acceptor of action (P. K. Anokhin, 1962). P. K. Anokhin, who conducted special experiments on animals, proved that "the respiratory center reacts immediately to feedback concerning an inadequate peripheral result by intensifying significantly its efferent impulsations."[27]

In our examples, reflexes represent reactions of nerve centers that develop in man (and animals) through heredity, and they are called unconditioned. They have the distinction that they appear at a time when some environmental factor that stimulates receptors has already begun to be active. For optimum adaptation of the body to environmental conditions, which change constantly, unconditioned reflexes alone are not sufficient.

The organism requires reactions that would prevent the effects of some environmental factors and that would appear in response to stimuli that are signals of possible appearance of such factors. It is very important for man to be able to avoid a present danger, by means of knowing about it in advance through signals. Reflexes that develop in man and highly developed animals in the course of individual development are such signals. Since these reflexes are formed only under specific conditions, I. P. Pavlov called them conditioned. For a conditioned reflex to form, the effect of some previously neutral stimulus must precede the effect of a stimulus that elicits an unconditioned reflex. Formation of new conditioned reflexes, specification, stabilization and refinement thereof occur in the cerebral cortex. As stated by I. P. Pavlov, there is bridging of a temporary connection between cortical centers in formation of a conditioned reflex, for example, the hand can be pulled away not only after exposure to a specific stimulus, but sooner, already at the sight of it. In the conditioned reflex, excitation that spreads over the nervous system reaches the cerebral cortex, where a temporary connection is made between cortical centers of different analyzers and motor centers. This means that if excitation arises in the nerve centers of analyzers (in the cortical representation of a given analyzer), it arises simultaneously in the cortical motor centers (cortical representation of the motor system). From them, excitation travels to the motor centers of the spinal cord.

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Periodic reinforcement, i.e., renewal of action of the unconditioned reflex, on the basis of which a given conditioned reflex was formed, is an important prerequisite for retaining and defining this new conditioned reflex. If there is no reinforcement for a long time, the conditioned reflex will become extinct under the influence of inhibition.

There are also reflex actions in work behavior. When a lathe operator turns a part on a lathe and changes from one operation to another, from one movement to another, he executes a series of reflexes. For example, when the cutter comes close to the notch on the part, the operator turns off the power feed, then turns the lathe off also. After the lathe stops, he moves the cutter away, takes a measuring instrument, makes a measurement, etc. In this sequence of actions, each successive action starts in response to specific changes that occur in the technological process, and each properly performed action receives conditioned reinforcement in the form of a change in state of the object of labor stipulated in the work instructions.

On the basis of the outward similarity of human actions and reflexeses observed in animals, some foreign scientists believe that one should study human behavior as purely conditioned reflex activity, without consideration of processes of consciousness and its psychophysiological basis. For example, John Watson suggested that one consider man as an organism that lives and moves without realizing what it does. According to his theory of behaviorism, the nature of reflection by the brain of reality, indivisibility and differentiation of perception, interpretation of associations and relations, etc., are not important to an explanation of human behavior. In the opinion of J. Watson, the human body performs different movements haphazardly, with many trials and errors, and solves the motor problem before it as a result of selection of movements that are reinforced by achievement of a result. Such simplistic determinism in the study of human behavior rules out determination of the role of mental phenomena in behavior of the personality. The latter is virtually entirely equated with animal behavior. "... If a psychologist wants to retain a scientific position," writes Watson, "he should not describe human behavior in terms other than the ones he would have used to describe a bull that he has led to slaughter."[28]

Logical development of these views results in negation of ideology and morals in human behavior, as well as other traits of the human personality and its social nature.

It should be noted that I. P. Pavlov, the founder of the teaching on conditioned reflexes and higher nervous activity, foreseeing the possibility of such narrow interpretation of his discoveries, dissociated himself from such extreme, biologizational simplifications of the problem of human behavior. Insisting that "our upbringing, education, discipline of all sorts and all sorts of habits constitute long series of conditioned

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reflexes," he warned that "one should wait patiently until precise and full knowledge about our supreme organ, the brain, will become our real possession, and with it the main foundation for durable human happiness."[29] I. P. Pavlov stressed: "It would be extremely foolhardy to consider the first steps in physiology of the cerebral hemispheres, complete in program only but not, of course, in content, as the solution to the tremendous problem of higher mechanism of human nature. For this reason, any narrow regulation of work on this subject at the present time would merely be an indication of extreme narrow-mindedness."[30]

Industrial physiologists and psychologists are faced with the task of defining the specific patterns of higher nervous activity of man. Labor is the basic distinction of man, as compared to animals. In labor, as a collective form of activity, there is development of communication between people, mutual understanding on the basis of common work goals. For this reason, accuracy, fullness, meaningfulness and objectivity of reflection in consciousness of man's own activity and the collective work process acquire decisive significance.

Stimuli that appear in group work activity constitute a unique category of stimuli. There exceptionally high intensity is manifested by the fact that they not only elicit a specific reaction, but alter the state and course of human vital processes, and at the same time elicit sensations and conceptions reflecting the properties of the natural and social environment.

The data obtained by industrial physiologists from studies conducted under production conditions are indicative of the physiological significance of socially determined stimuli. In a study of physiological processes in workers engaged in mechanized accounting, T. N. Pavlova (1956) measured the critical frequency of disappearance of phosphene (sensation of flickering light induced by delivery of weak, intermittent current to the optic nerve). It was found that, in an ordinary production situation, man ceases to notice phosphene when the frequency of electirc stimulation is increased to 40 Hz. During the experiment, the subject was told that there is a telephone call for him. He asks who is calling. He learns that a friend is calling. This is associated with an increase to 45 Hz in critical phosphene frequency. When the subject is called in by the shop supervisor, the critical phosphene frequency constituted 80 Hz and when called in by the director it was 120 Hz. Thus, there is a change in functional lability of the human nervous system under the influence of socially determined stimuli.[31]

Motor reactions to stimuli while performing work operations differ from other reactions in that they are directed toward creating use values. As a means of producing use values, they may be significant, not in the form of separate movements, but necessarily in a combination of various motor and mental actions constituting the dynamic work stereotype, i.e., a system of

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reflexes that solves a specific work problem and receives reinforcement in the form of a useful result that is meaningful to satisfaction of society's needs (S. A. Kosilov, 1957).

The capacity to form reflex systems is inherent, to some extent, in higher animals. Such associations of elementary conditioned reflexes were obtained in research conducted on dogs by I. P. Pavlov and his coworkers. Conditioned salivation reflexes in response to various stimuli (for example, metronome beat, lamp lighting up, "kasalka" [tapper]) were developed in experimental animals. Then these conditioned stimuli were always used in the same order. The animals responded to a series of such stimuli with a series of reflexes in the same order. A specific amount of saliva was produced in response to each conditioned stimulus. The series of reflexes occurred in the original order with change in order of stimuli. I. P. Pavlov called such a combination of reflexes into a single system the dynamic stereotype.

There is a basic difference between the dynamic work stereotype and the dynamic stereotype inherent in animals. Verbal stimuli, or stimuli of the second signaling system, in the form of instructions by an instructor, foreman, written instructions and blueprints, are among the stimuli to which man reacts as he performs work operations. There is a large number of components in the dynamic work stereotype, whereas there can be no more than four components in the stereotype of animals. The dynamic stereotype of animals is reinforced by an unconditioned stimulus, which elicits some natural reaction (for example, salivation, defensive movements, etc.), while the dynamic work stereotype is reinforced by achievement of a socially useful result from the motor reaction, which consists of competent movements, formulation of verbal reports, execution of blueprints, diagrams, tables, etc.

The social nature of labor determines man's ability to form very complex reflex systems in the course of work, and to use as reinforcement and maintenance thereof signals about effective attainment of the result of labor. This distinction of man is inherent in him as a social being, the behavior and vital functions of which are governed by social laws. For this reason, simpler and more common biological laws, which are in effect under the special conditions of social relations, become more complicated, enriched with new content, and they are transformed into more complex special (effective in a narrower area of application) sociobiological and psychological laws.

The dynamic work stereotype is the unit of human behavior as a social being. The patterns of formation, maintenance and refinement of the dynamic work stereotype constitute the typical distinction of man from all other living things. Knowledge of these laws [patterns] makes it possible to find adequate means of controlling vital functions, man's work and social activity, as well as the means for rational organization

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of industrial training, job placement, vocational guidance and development of work creativity. One explains how, in the presence of the second signaling system, man plans his actions in accordance with verbal instructions he receives, on the basis of the laws of formation of the dynamic work stereotype. Verbal stimuli are forceful and meaningful because they help man to experience again prior states inherent in previously performed work processes, to receive the corresponding sensations, to form conceptions about prior and future work activity.

Words that a man hears or reads help him in forming a conception of the goal of a work action and means of reaching it. By means of verbal instructions, man acquires the physiological basis for planning and regulating work actions. In response to audible or visible combinations of the appropriate words, a man becomes more animated and there is intensification of stimulation which had remained, in the form of slight traces, in his central nervous system from prior activity, which is the physiological basis of the conception of the goal of work, plan and means of reaching this goal.

The system of traces of nervous excitation, which are revived with the appropriate verbal stimuli, constitutes the basis of programming of specific work behavior, and it is made up (depending on the content of the industrial work task) of processes that include the function of different parts and points in the central nervous system. There can be traces here of excitation of different sense organs, excitation of diverse quantitative nuances, combinations and sequences.

Since sensations and reflexes that recur with revival of traces of excitation are elicited by previously perceived objects which are not present in the immediate vicinity at the present time, we are dealing with the image of these objects, events and actions. An image that is made up of many trace elementary work processes is called the integral image of work actions.

Neurology has helped determine approximately the regions of the central nervous system where processes occur that make up the material basis of the integral image of work actions. Observations of patients with injuries in the frontal region of the brain merit attention. Such patients have difficulty in performing relatively complex programs of motor activity. It is difficult for them to place checkers in a specific order (for example, a row of two white and one black checker, etc.), or to draw figures in some order (for example, a row of two crosses and one circle, etc.). Observations of such patients revealed that the main difficulty in executing a program of actions is referable to self-monitoring, evaluation of their own actions and detection of their own mistakes. Patients repeat correctly the instructions they are given and can readily detect mistakes made by someone else in executing the same program. Neurologists and psychiatrists believe that the inability to execute

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relatively complex programs, which is associated with massive lesions to frontal lobes of the brain, is related to impaired formation of preliminary syntheses and defects referable to signaling and regulatory function of speech, as well as impairment of the mechanism of comparing the effect of one's own action to the initial one.[32]

A fuller idea about the localization of excitatory sites in the cerebral cortex during formation of an integral image of work actions was obtained from studies of movements in simulation of work activity.

We have tracked the involvement of higher branches of the nervous system in formation of the integral image of work actions (S. A. Kosilov, A. I. Vasyutina, A. A. Rigina, 1970) on the model of accuracy of depressing a lever (Figure 4).[33]

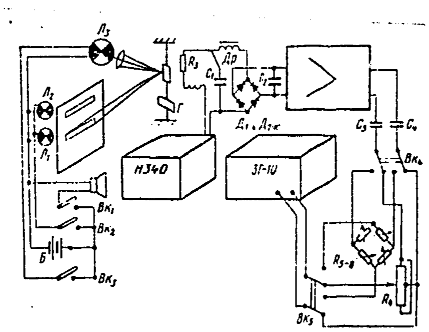

Figure 4. Simplified diagram of recording bioelectrical activity of muscles and cerebral cortex during performance of precision movements

>) amplifiers and recording devices of electroencephalograph, on which action currents of muscles and different regions of the cerebral cortex are recorded

R_{5-8}) resistance bridge, one arm of which is a sensor of movements in radiocarpal joint

ЗГ-10) sound generator whose signals are delivered to one of the EEG circuits over bridge R_{5-8} (the amplitude of these signals changes in accordance with bridge imbalance)

Н340) automatic recorder tracing movements on a larger scale

Г) mirror galvanometer for visual monitoring of movements in radiocarpal joint

$Л_3$) lamp with lens directing beams to mirror and screen

Bk) switch

Д) sensor

C) adder [?]

Б) battery [?]

The subject was asked to bend the arm in the radiocarpal joint to move the kinesthesiometer lever so that the control line on the oscilloscope screen would reach a specified level.

Before starting this test, electrodes were attached to the subject's head for derivation of bioelectrical potentials from different parts of the

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cerebral cortex. While the subject performed specified movements, the electroencephalograph recorded the mechanogram of precision movement, biopotentials of muscles (extensors and flexors of the radiocarpal joint), bioelectric potentials derived from points on the skull over the frontal, temporal, parietal and occipital regions of the cortex. Electrodes fixed over the frontal region transmitted potentials of nerve centers related to programming of activity. The instrument recorded the action potentials related to formation of motor impulses, perception and analysis of stimuli of nerve endings in muscles, joints and tendons (kinesthetic stimuli) by means of electrodes placed over the central region (over the sensorimotor and motor regions of the brain, where the anterior and posterior central gyri of the cerebral cortex are located). Electrodes fixed over the temporal region transmitted information about bioelectrical potentals related to tension of the auditory analyzer; electrodes fixed over the occipital region transmitted potentials related to tension of the visual analyzer.

We had to determine how the accuracy of a specified movement would change in relation to organization of monitoring of these movements and involvement of various analyzers and various regions of the cerebral cortex. It was assumed that under diverse conditions of additional monitoring [or control] in the cerebral cortex, a different integral image will be formed and, accordingly, different distribution of activity of nerve centers that constitute the physiological basis of behavior in accordance with the integral image.

Students 16-17 years of age participated in the experiment. We conducted four experiments on monitoring of performance of precision movements. In the first experiment, we used kinesthetic analysis of motor activity without additional signals from other analyzers. At first, the subject performed three movements with a specified amplitude, in accordance with movement of a light signal on the oscilloscope screen; then (after the integral visual-motor image of action was formed) he performed the three movements without a light signal. The actions of the subject were based on an already formed image and corresponding traces of nervous excitation in the cortex.

In the second experiment, there was constant visual monitoring of movements. In the third, the subject was informed of mistakes made after performing a movement without additional monitoring. In the fourth experiment, there was concurrent visual and verbal monitoring [control].

Figure 5 illustrates tracings of mechanical and bioelectrical processes. In our analysis of the findings in each experiment, we took into consideration several parameters, including precision of movements. Precision of movements was characterized by the magnitude of deviation of motion from specified amplitude. The corresponding values were determined from entries on a separate chart. We determined the duration of the latency

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period of motor reaction, i.e., the time from delivery of signal about start of movement to start of performance of movement. On the combined EEG tracing, this parameter is shown on the top line. Then we determined the duration of the desynchronization (increased rhythm of oscillations with concurrent decrease in their amplitude) latency period. This period begins at the time of delivery of the signal and lasts to the time of radical change in EEG rhythm.

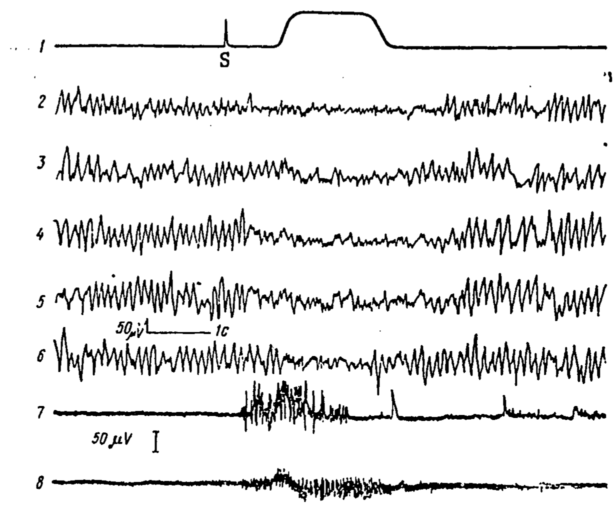

Figure 5. Tracings of bioelectric potentals of muscles and cerebral cortex during performance of precision movements

1) mechanogram of movement (S--mark of signal to start movement)
2) bioelectric potentials of left frontal cortex
3) bioelectric potentials of left temporal region
4) bioelectric potentials of left central region
5) bioelectric potentials of right central region
6) bioelectric potentials of left occipital region
7) bioelectric potentials of muscles that bend the arm in the radio-carpal joint
8) bioelectric potentials of muscles that extend the arm in the radio-carpal joint

The scale of amplitude of bioelectric potentials (μV) and time (s) is indicated on the oscillogram.

It is generally believed in neurophysiology that an increase in frequency of bioelectrical oscillations on the EEG with reduction of their amplitude is

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indicative of an arousal reaction, increased excitability and interest in stimuli from the surrounding environment.

The effect of the arousal [awakening] reaction is indicative of complex interrelations and feedback between neurons of the cortex and subcortical structures. When there is limited delivery of afferent impulses to the cerebral cortex (when the eyes are closed, when in a state of rest in a quiet and dark room), slow, high-amplitude waves (alpha waves at a frequency of 8-13/s, delta and theta waves at a frequency of 0.5-0.8/s) are observed on the EEG. But if afferent impulses are delivered to the cerebral cortex and a man is in a waking state, the electroencephalograph records high-frequency, low-amplitude waves (oscillations of the beta wave type with frequency in excess of 13/s). Special studies have established that in a waking state impulses are delivered to the cerebral cortex from those regions of the mesencephalon where cells with a special structure are localized, which form the reticular formation. In order to perceive stimuli from sense organs, nervous impulses travel to the cortex over special sensory nerves; in addition, the cells of the reticular formation send nonspecific impulses to the cortex, which determine the arousal effect. The duration of the latency period of bioelectrical activity of muscles is noted on tracings of bioelectric potentials of the muscles.

The described group of bioelectrical parameters characterized the development in time of preliminary preparation for movements. A movement is prepared, according to data on duration of latency periods, first in the cerebral cortex (where the system of traces of excitation corresponding to the integral image of actions is apparently formed or renewed). Somewhat later, there is preparation for the reaction of muscular contraction and, finally, movement begins.

A comparison of the degree of precision of performance by the subjects of a specified movement with the different variants of additional monitoring revealed that maximum accuracy (minimum error) was achieved with combined verbal and visual monitoring, it was somewhat lower with visual monitoring and lowest with verbal monitoring (Table 4). Data on accuracy of the mechanical effect in the absence of additional monitoring by kinesthetic analysis were characterized by lowest accuracy and wide scatter of numerical values. The group of subjects who worked without additional monitoring was divided into two subgroups, according to accuracy of results (subgroup A, subjects presenting greater accuracy of results and subgroup B with lesser accuracy). We found that, in subgroup A, the latency period of the motor reaction was longer on the average, while the latency period of desynchronization of bioelectrical processes in frontal and central regions was shorter than in subgroup B. This indicates that prolonged preparation for movement (formation and renewal of traces of excitation) in those cortical regions where the programming centers (frontal region) and centers used for kinesthetic analysis (central region) are located is instrumental in increasing accuracy of movement.

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Table 4. Parameters of desynchronization of electroencephalographic oscillations (EEG) in different parts of the cerebral cortex of students 16-17 years of age during performance of precision movements under different monitoring conditions (data of S. A. Kosilov, A. I. Vasyutina and A. A. Rigina, 1970)

Variant		Ia	Ib	II	III	IV
Type of monitoring [control]		without additional monitoring	without additional monitoring	visual monitoring	verbal monitor.	visual & verbal monitoring
Accuracy (deviation from specified amplitude) in instrument scale graduations		10,5±0,39	20,6±2,07	2,6±0,17	4,8±0,29	1,2±0,07
Latency period of EEG desynchronization, m/s	In frontal region	182,7±4,55	361,1±16,80	356,0±8,50	104,5±5,65	200,5±7,87
	In temporal region	405,0±13,10	360,0±38,21	402,0±10,85	120,0±6,95	205,3±8,22
	In central region	250,8±11,95	382,0±30,31	355,0±12,80	195,5±15,71	245,4±15,0
	In occipital region	580,0±15,70	559,5±46,0	330,9±12,22	430,0±17,60	220,0±9,53
Duration of desynchronization, s	In frontal region	12,9±0,55	7,0±0,53	17,4±0,69	13,5±0,77	16,7±0,99
	In temporal region	12,6±0,51	7,0±0,90	16,2±0,81	13,3±1,04	16,6±0,97
	In central region	13,4±0,62	7,0±1,35	16,6±0,78	12,7±0,66	16,1±0,01
	In occipital region	11,9±0,52	6,8±1,12	17,6±0,79	11,4±0,60	16,4±0,70

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It is also remarkable that when the subject was not given the task of achieving a certain accuracy, as in the case of a simple motor reaction, the latency period of the motor effect was shortest, and there was no desynchronization in the cerebral cortex, or else it had a long latency period (consequently, in this case, there was minimal preparation for movement and formation of excitatory traces).

We must mention the increased duration of desynchronization in the cerebral cortex with achievement of a high level of precision of movements. This indicates that the most useful effect of work actions is obtained with rather stable traces of nervous excitation. Finally, it is also important to physiological analysis of the essence and manifestations of the integral image of work actions that, depending on the distinctions of organization of monitoring of performance of movements and involvement of some combinations of analyzers or other in such monitoring, there is a change in intensity of traces of excitation in the corresponding regions of the cerebral cortex (see Table 4).

Thus, the shortest latency period of desynchronization and longest period of desynchronization were observed in the frontal and central regions, i.e., in the centers for programming and sensorimotor centers, and they are typical of concentration of monitoring on the program of movements and kinesthetic stimuli. When performing movements under visual control, the shortest latency period of desynchronization and longest duration of desynchronization were observed in the occipital region, i.e., where the centers of visual analysis are localized. When performing movements under verbal monitoring, signs of maximum intensity of preparation for precision movements (shorter latency period of desynchronization and stabler trace effects) are typical for the temporal region, where the centers for auditory analysis are localized.

This example of formation and renewal of the system of traces of excitation during the period of preparing for a precision movement indicates that the integral image of a work action is not only a hypothesis, which is expounded as a logical necessity to explain the distinctions of work behavior, but a physiologically proven real fact, which has a material basis in concrete processes occurring in specific regions of the cerebral cortex.

New routes for rational organization of the work process are being disclosed in studies of work behavior and changes in functional state of different centers of the cerebral cortex.

One of these routes is the introduction of measures that aid in formation of the appropriate and complete integral images of work action. Another route is the use of steps that aid in becoming aware of the elements of the integral image. Practical pedagogics and psychology make extensive use of the didactic principles of awareness [consciousness] in training and education, and they enrich motor and work experience by influencing the

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consciousness of students and controlling [monitoring] their conscious behavior and statements. Awareness of progressive work skills, which are refined on the basis of the correct integral image of the required work action, is very important to dissemination of progressive knowhow.

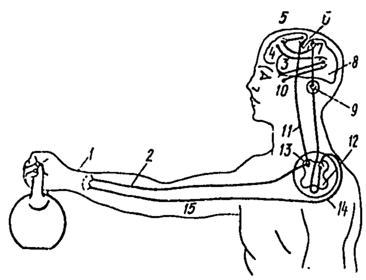

Figure 6. Diagram of reflex cycle of control of motor system involved in holding weight, based on data in neurology and physiology of movements

1) functional connection between activity of motor nerve inducing muscular contraction (2) and perception of stimulation of nerve endings in these muscles and adjacent tissues (tendons, joints)
3) optic nerve
4) programming centers
5) anterior central gyrus of cerebral cortex
6) central cortical sulcus
7) posterior central gyrus of cortex
8) cortical optic centers
9) thalamus, site of decussation of sensory nerves
10) oculomotor nerve
11) pathway of motor impulses (pyramidal pathway)
12) spinal cord (transverse section)
13) motor cell
14) sensory cell
15) pathway of excitatory impulses (proprioceptive impulses) arising in nerve endings, which are situated in the motor system

One can form an idea about the processes of control and regulation of motor actions of man, which must be performed under the influence of physiologically substantiated organizational measures, on the basis of physiological analysis of the above examples. These measures affect both the conscious work behavior and components of the integral image of the dynamic work stereotype, which remain below the consciousness threshold in the first signaling system.

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Let us consider an example of the simplest work action, holding a weight in the hand. Figure 6 illustrates the travel of nervous excitation when performing this action. It illustrates the dissemination of nervous excitation from the central nervous system to muscles, the contraction of which balances the force of gravity of the hand and weight. This is a direct association in the self-regulating functional system. It appears when performing a specific work task involving use of the mechanism of bridging conditioned associations reinforced by attainment of a specific work goal. Feedback in this system is represented by two pathways of nervous impulses traveling from the sense organs to the central nervous system: from the retina, which is exposed to the flux of light and from which excitation travels to centers that visually perceive the weight and position of the hand that is holding it; from sensory endings in muscles, joints and tendons. Muscular tension and the position of elements of the arms in the corresponding joints are perceived by means of the second afferent pathway. Information travels over each of these pathways about performance of an industrial task, holding the weight, that is important in a specific segment of time.

Let us analyze some of the cycles of regulation that are formed by associations and feedback in this reflex functional system. The main stages of the first cycle are: the retina, optic nerve, optic centers in subcortical structures of the brain and cerebral cortex, programming centers in the frontal cortex, anterior central gyrus where cortical motor cells are concentrated, pyramidal tract--neural conductors traveling in the anterior columns of the spinal cord to motor cells of the anterior cornua of the spinal cord and from them to actuating organs--muscles, contraction of which develops the force that balances the weight and elements of the arm. This cycle is closed by the flux of light from visible objects (weight and arm) to the retina. At these stages of the cycle, the concrete carriers of information change several times: information comes to the retina from electromagnetic oscillations of the flux of light, in the retina itself photochemical processes of disintegration of a light-sensitive substance, rhodopsin, are involved in perception of information. The subcortical optical centers receive information from the retina in the form of a flow of nervous impulses, in each of which the electrical action potential plays a significant role. At the sites of passage of excitation from one neuron to another (in the synapses), transmission of information occurs by means of chemical transmitters. In muscles, information is received by muscle cells which contract and impart the required position to the arm.

Only one physicochemical property of information carriers is very important to transmission of information, that of transmitting without delay and distortion (noise) the content and amount of information that can be coded in different ways and properly decoded at its destination.

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As far back as 1929, in an article entitled "Passage of Excitation From Cell to Cell," A. F. Samoylov mentioned the significance to reflex activity of the principle of circular movement of processes that implement transmission of nervous excitation in the organism. A. F. Samoylov wrote: "Let us now imagine that an animal contracts its muscles and there is a movement that is associated with sounds, for example, steps, the sound of a voice. These sounds elicit chemical stimulation of sensory endings of the acoustic nerve. Thus, a closed circle is formed again, and part of it is in the exogenous environment.... Stimulation of the retina is, no doubt, based on a chemical process, namely a photochemical one. The movements of parts of the body and exogenous objects elicited by muscles when the animal inspects them induce prolonged stimulation of optic nerves. We are again faced with a closed circle, which also includes the exogenous environment."[34]

Demonstration of the principle of circular movement of information in nervous regulation is very important to research and development of scientific and practical recommendations in industrial physiology, since it permits the study and then transformation of association between different elements of reflex systems that determine man's work behavior, i.e., dynamic work stereotypes.

The stages in the second cycle of nervous regulation are as follows: optic nerve, visual centers of subcortical structures and the cerebral cortex, programming centers, oculomotor centers, oculomotor nerves and muscles. This cycle is also closed in the exogenous environment by a flux of light. Its purpose is to fix the eyes on the position of the arm controlled [monitored] by a man while holding a weight.

The oculomotor nerve travels to the muscles of the eye, directing the axis of the eyeball on the monitored objects. Thanks to the presence of six muscles, the eyeball can rotate about any axis that traverses its center. There are fibers in the oculomotor nerve over which impulses come from the mesencephalon, which induce contraction of the ciliary muscle that controls the shape of the lens (optical system of the eye).

The third cycle of nervous regulation of the simple work act of holding a weight implements the travel of information within the motor system. In it, feedback is formed by nerve fibers traveling from sensory nerve endings of the motor system via sensory nerves, through the spinal cord and thalamus, to the central gyrus of the cerebral cortex,[35] and from there to the programming center.

The connection that started in the programming centers continues over neural conductors traveling to the anterior central gyrus of the cerebral cortex where neural motor impulses arise. The latter travel over the pyramidal tract of the spinal cord to the motor cells of the anterior cornua of the spinal cord and from them to muscles. The cycle closes with a functional connection within the motor system. This connection

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consists of the fact that the motor impulses from cells of the anterior cornua of the spinal cord maintain muscular tension. Excitation in sensory motor endings arise because of mechanical tension of muscles, connective tissue and deformation of the layer of articular surfaces.

A distinction must be made within each of the cycles of regulation we have discussed between impulses that have trigger meaning, which take the initiative in implementation of the program outlined in the frontal cortex, and corrective impulses. The latter are reactions to impulses traveling over feedback channels and reporting a discrepancy between the actual position of the arm and the position specified in the program.

In the example we have discussed, different elements of neural regulation of a simple, voluntary work action have been described schematically. In this analysis, we have deliberately omitted many important details. In particular, it does not consider the role of nerve centers situated in the cerebellum, the function of retaining equilibrium, respiratory and circulatory functions during performance of a work task. The objective of our analysis was merely to demonstrate the principle of cyclic neural regulation of work processes and the significance of transmission of information, existence of a program, integral image of work action and the necessity of formation of a functional reflex system, the dynamic work stereotype.

Let us discuss the physiological mechanism that assures the stability of this reflex system, in particular, its accurate and perfect function in the presence of chance interference.

Numerous stimuli, which change every second, affect the human sense organs, their special devices that are adapted to perception of effects of different forms of energy, i.e., receptors. If the body would react appropriately to each stimulus, behavior would dissolve in the chaos of these stimuli and would lose all purposefulness. But this does not happen in the normally functioning organism because movements or reflexes that are superfluous for a given activity are excluded thanks to a special function of the nervous system, inhibition.

Inhibition consists of the fact that nervous impulses going to a performing organ do not enhance, but inhibit the function of this organ. We are well-aware of instances in everyday life where superfluous movements are eliminated by skilled workers, there is voluntary suppression of movements that result from pain, fear, etc. Suppression of activity that is not important to a given element of activity is an important inhibitory function of the nervous system.

Work actions are defined and attention is kept on a limited range of phenomena that are of greatest interest thanks to neural inhibition.

Inhibition is the opposite of excitation only in its ultimate effect. Excitation spreads over a nerve concurrently with inhibition (reflex

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phase). Excitation or inhibition may arise in an effector organ, depending on the change in membrane potential. If the latter increases in a cell there is hyperpolarization of the cell membrane. In this case, the threshold of excitation increases and the force of stimulation must be increased to induce excitation. Another mechanism of nervous inhibition refers to the fact that, in the case of very frequent nervous impulses traveling to a neuron from one or several related neurons, there is persistent depolarization of the cell membrane, i.e., loss of electric charge in the cell, as a result of which the cell becomes unexcitable. Inhibition can also arise under the influence of certain chemical compounds, which alter the electric charge of a cell.

The study on animals of the results of electric stimulation of segments of the medulla containing cells with a special structure, the cells of the reticular formation, is important to development of the problem of nervous inhibition.

Let us discuss in greater detail the characteristics of the part of the nervous system known under the name of reticular formation.

The reticular formation is located in the central part of the brain stem.

The reticular formation differs substantially in structure from the nervous tissue around it. The latter is characterized by accumulation of neurons forming so-called nuclei and accumulations of conductors (which are processes of neurons), the conducting pathways. The physiological significance of the reticular formation was demonstrated by means of delivery of destructive and stimulating agents to precise locations.

For example, this is how it was established that electric stimulation of the reticular formation of a waking animal induces interest in events occurring in its surroundings. If the same regions of the nervous system are stimulated in a sleeping animal, it will stay awake, and action currents will appear in the cerebral cortex that are inherent in the waking state. These findings served as grounds to believe that "encouraging" impulses travel from the region of the reticular formation to the cerebral cortex and that there is a special ascending, reticular activation system. The American physiologists, H. Magoun and R. Rhines[36] have established that electric stimulation of segments of the medullar reticular formation of animals inhibits spinal cord reflexes. A more comprehensive study of functions of the reticular formation revealed that it has areas that inhibit and activate spinal cord reflexes.

The reticular formation receives excitatory impulses when different analyzers (sense organs) are stimulated. When receptors are stimulated, the excitation that arises in them spreads not only to the appropriate nerve centers of the cerebral cortex, but over branches of neural conductors (over collaterals) to the reticular formation. Impulses travel to the

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cerebral cortex from analyzers over two pathways: a specific one, from receptors to specific sections of the cerebral cortex, and a nonspecific one, via the reticular formation to all parts of the cerebral cortex, thereby increasing the readiness of cortical neurons to receive new signals. Stable function of reflex systems is possible if both pathways are intact and in normal condition. Impairment of the specific pathway leads to functional impairment of one of the analyzers, while impairment of the nonspecific pathway deprives the animal of the possibility of perceiving any stimulus, and it sleeps.

In observations of patients who had undergone brain surgery, action potentials were derived from the optical conduction pathways. Potentials were recorded that reflected flashes of light perceived by the eyes. These potentials disappeared or weakened if stimuli that distracted the patient's attention were delivered. On the basis of the results of experiments conducted on people and animals, it was established that new stimuli and changes in the environment activate the reticular formation, which receives the new stimulus and inhibits conduction of excitation to other analyzers. Physiologists believe that expressly the reticular formation is actively involved in excluding from attention stimuli of secondary importance and in enhancing the effect of meaningful stimuli.

Now we can include the reticular formation in the previously discussed simplified scheme of neural regulation. If impulses that implement proper eye position are transmitted from the programming center in the cerebral cortex to the centers of the oculomotor nerve, there is concurrent (with a slight lag) delivery to the same centers of impulses from the reticular formation, which may enhance or diminish the perceptive capacity of the eye. The reticular formation has the same regulatory effect on other receptors. For example, excitatory impulses travel to muscular receptors over special nerve fibers (gamma fibers), and they enhance the sensitivity of muscular receptors to mechanical tension, eliciting preliminary tension in them. Thus, the sensitivity inherent in a concrete receptor at a given moment depends on the state of man, his needs, biological or social significance of the behavioral act he is performing.

The distribution of processes of neural excitation and inhibition in the organism is based on the dominanta principle. A. A. Ukhtomskiy (1923) introduced the term dominant to refer to "a more or less stable site of heightened excitability of nerve centers, whatever induced it, and new stimuli entering the centers serve to enhance (confirm) excitation in the site, whereas in the rest of the central nervous system there are widespread signs of inhibition."[37] A. A. Ukhtomskiy arrived at this conclusion as a result of laboratory studies of animals' motor behavior. If motor points of the cortex (points, stimulation of which usually results in specific movements of the limbs) are stimulated in animals with exposed cortex at the time preceding defecation, the expected movements will not occur and defecation will occur sooner. Stimulation of these motor points during the swallowing reflex enhances this reflex

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and inhibits the usually occurring movements of the extremities. The dominanta is manifested in behavior of an animal or man as a whole by the achievement of a specific biological goal, for example, sexual, food-related, defense and other dominantas.

A. A. Ukhtomskiy described the state of excitation of the dominanta as the set of the following features: "1) heightened excitability: the threshold of excitability in the center that becomes dominant must be at least equal in magnitude to the stimulus that is delivered to it in the form of a remote wave of excitation; 2) stability of excitation: for the excitation that began in the dominanta under the influence of the remote wave to be able, in turn, to influence the course of a reaction, this excitation must not be brief; 3) capacity for summation of excitation[38] with a given force and frequency of afferent waves; 4) inertia, with which the significance of remote waves refers mainly to 'encouragement' and acceleration of established dominant reaction in the direction of its resolution."[39]

* * *

In this chapter, we have tried to demonstrate the significance of the study of physiological processes to further refinement of organization of labor on a scientific basis. Rational use of work time, elimination of unproductive work time and energy have definite sources in physiological processes. The study of these processes indicates that a saving of work time is obtained largely by improving work movements and, in particular, by assimilating the standards [normals] of movements. But assimilation of standards and refinement thereof by industrial innovators are based on formation of dynamic work stereotypes and integral images of the required work actions.

The dynamic work stereotype and integral image constitute the physiological basis of such mental qualities in a skilled worker as planning work operations, self-monitoring of work performance and accumulation of professional knowhow. In turn, the dynamic work stereotype and integral image of work action are formed and refined if there is motivation for work behavior based on the work dominanta. Disclosure of the order of these processes in work activity and control thereof constitute a reserve, which is still little-used, for saving work time and increasing labor productivity.

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CHAPTER 4. PHYSIOLOGICAL LAWS OF ACTIVE ADAPTATION TO WORK, AND METHODS OF CONTROLLING THE DEVELOPMENT OF MAN'S NATURAL INCLINATIONS

The diverse physiological processes constituting the material basis of activity are not totally reflected in consciousness in the course of man's vital functions. Elements of performed movements, components of the integral image, programming, afferentation of activity and other processes involved in accurate performance of work operations cannot be submitted to complete self-analysis by the worker, and they are objectively demonstrable only in special studies with the use of appropriate equipment. This is the reason why workers do not receive complete instructions when they undergo traditional training in work skills. The existing instructions on performance of work operations do not indicate the parameters for regulation of movements, although there are indications about the purpose of a technological operation, the specifications for the end product of labor, order of performance of operations, tools to be used and some of the features of work movements. The trainees must find the means of performing many elements of a work operation on their own, by means of numerous trials and errors, by comparing the end result to the standard. When learning a new occupation, the worker must be patient, concentrated, attentive, and he must be able to distinguish between accurate actions and poor variants thereof.

Patience is needed in order to endure fatigue and the effects of monotonous stimuli that are related to the many repetitions of studied work actions. Concentration should aid in withstanding distracting stimuli, which may appear during performance of the main activity. Concentrated attention is needed to become properly oriented in the technological process and to coordinate one's actions with changes in the object of labor. How can a trainee alter his behavior and subordinate it to the signle goal of acquiring a work skill? The only means of such a change is to master the appropriate dominanta, reflected in consciousness as motivation, or the main imperative of activity.

Pedagogic practice uses several training methods. One of them is the imitative reaction of man. In addition, one uses explanations of the industrial and social significance of the learned types of work.

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Work of trainees together with experienced workers is the most effective method of developing a work dominanta.

In this respect, the experience of industrial mentors is of great interest.

Having assimilated the work traditions of a group, the young worker begins to be governed in his actions by appropriate motivation, he develops work skills that are based on formation of the dynamic work stereotype and integral image of work actions. Formation of the dynamic work stereotype and integral image is aided by accumulation of traces of nervous excitation that remained after numerous repetitions of standard work actions and reinforcement of the best methods of performing these actions by work achievements.

The young worker revises his attitude toward work on the basis of a progressive work dominanta and awareness of the social significance of his work. He acquires more interest and respect for his profession. He develops a desire to learn new abilities and skills independently, to achieve high results and develop his innate inclinations.

It is impossible to assimilate work skills without a certain change in physiological processes in the body and without formation of the appropriate reflex systems, the dynamic work stereotypes.

According to the teaching of I. P. Pavlov, formation of the dynamic stereotype is nervous work. Systematization of stimuli and creation on their basis of the dynamic stereotype are, in the words of I. P. Pavlov, a "tremendous job." In the experiments of I. P. Pavlov, animals performed this job under the influence of the hunger dominanta. Before the experiments, they were kept without food for a certain time and thus acquired a very marked direction of behavior. The self-preservation instinct and presence of "hungry blood" poor in nutrients compelled the animals to search for food and to perform work instrumental in formation of a primitive stereotype of stimuli.

What the dynamic work stereotype, which is formed by socially determined stimuli and is referable to sociobiological phenomena, and the animal stereotype have in common is that this system of reflexes is capable of subordinating all processes in the organism. This subordination occurs in different forms, depending on the specific type of work, and it takes place gradually. While the meaning of a work action and industrial significance of a work skill are understood by a young worker relatively rapidly, the change in physiological processes that is required to acquire a skill occurs over a long period of time, sometimes for several years. The change in physiological processes as related to changes in conditions of interaction between the organism and environment is called adaptation.

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Adaptation to work activity constitutes a special category. The distinction of adaptation to labor is attributable to the fact that it aids in optimum adjustment to work mainly by means of more complex interaction with the environment, rather than escape from the influences of the environment. A widespread form of adaptation (passive adaptation) is reduction of the body's vital functions.

Thus, when there are deleterious changes in the environment (lower temperature, decreased amount of nutrients, humidity, etc.), many animals cease motor activity, begin to hibernate, go into anabiosis. This is associated with decreased sensitivity to environmental factors and increased thresholds of excitation of the corresponding organs. Adaptation of man to, for example, such environmental factors as noise, is referable to the same category.

As compared to passive adaptation to deleterious environmental factors, adaptation to work is active; it does not lead to increase of excitation thresholds, but to a decrease; it does not lead to a decrease of motor and cognitive activity, but to an increase; it leads to development of innate inclinations inherent in the organism. For this reason, it is valid to call adaptation to work active adaptation.

When organizing labor on a scientific basis, one must take into consideration man's active adaptation to work; one must develop and apply the theory and methods of controlling physiological processes that determine this adaptation. The uniqueness of physiological processes of active adaptation is that they not only aid in acquiring work skills but, at the same time, they develop the natural inclinations of a working man. Rational organization of labor must provide for development of inclinations for nervous regulation of work processes, programming and correction of work actions, i.e., the ability to increase accuracy of work operations and movements.

For rational organization of labor, it is imperative to determine which physiological processes are involved in perfecting work skills (and the corresponding dynamic work stereotypes) and in increasing the accuracy of work actions, in particular, the accuracy of work movements, as well as to develop methods for demonstration and quantitative evaluation of the level of development of these physiological processes, to determine how these processes can and should be controlled, to develop and transform them in the desired direction.

To answer these questions, we studied the precision work movements performed by workers differing in skill under industrial conditions, students at schools and vocational and technical institutions, and models of these movements performed under laboratory conditions.

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Work was studied in the laboratory using a special instrument, the kinesthesiometer (S. A. Kosilov, 1974). The subjects had to depress a lever. The precision of depression was monitored by signals with varying modality (light signals, verbal indications by the experimenter, kinesthetic stimuli).[40] In addition, studies were made of movements involved in filing metal. Bench vises were equipped with signal lamps that lit up if movements were inaccurate (instant correction of movements). In another series of studies, a miniature projector was attached to the tip of the file, by means of which there was continuous correction of movements. The projector beam could not exceed the band shown on a screen. As a result of training, the subjects acquired considerably improved accuracy of movements, with fewer deviations from the standard movements.

Introduction of additional reference points signaling mistakes and accurate movements helps increase the volume of information received through the feedback channel in the reflex system of the dynamic work stereotype. In the scheme of self-regulation of movements which we discussed previously, we see that self-regulation is implemented by delivery of kinesthetic and visual feedback signals to the nervous system. Feedback must be borne in mind when developing rational work movements, and it must be used whenever it is necessary to have very accurate movements. The beneficial effect of additional information is demonstrable immediately after it is introduced.

Accuracy of movements is also improved by means of properly organized, systematic training. In this case, the beneficial effect is obtained gradually, after numerous repetitions of movements. The effect of training is based on the physiological mechanism of summation of traces of nervous excitation.

Nervous excitation spreads over an axon without any prolonged residual aftereffect. After the first impulse travels through an axon, another impulse and series of impulses can pass through the same axon at the same speed. After each impulse, a slowly regressing excitatory trace remains in the neuron. The nervous impulses arising successively in the cell also leave in it a series of interacting traces of excitation, which leads to a change in functional state of the neuron that is characterized by excitability and lability,[41] or functional lability. Excitability is measured by the level of the threshold, i.e., lowest intensity of a stimulus capable of eliciting excitation. With interaction of traces of excitation of moderate intensity (in the case of relatively long intervals between successive stimuli), summation of traces of excitation not only accelerates the response, but enhances excitability and lability of nerve centers, and increases the speed of development of reflex processes.

The physiological mechanism of summation of traces of nervous excitation plays the main role in active adaptation to work and, in particular, assimilation of precision movements. During development of precise movements,

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induced by summation of traces of excitation, the increase in excitability and lability was manifested by increased sensitivity of the kinesthetic analyzer, sensitivity of the set of analyzers, functional lability of the motor system and formation of the integral image of the required precise work movement.

The level of kinesthetic sensibility of subjects (12-year-old school boys) was measured according to differential threshold of determination of the weight of different weights. It was found that, in the course of training, all of the subjects showed a reliable increase in kinesthetic sensitivity, which developed gradually, with summation of traces of nervous excitation. The ultimate result of training differed in different experimental groups, depending on the volume of information received by the nervous system via feedback.

The parameter of kinesthetic accuracy increased by a mean of 28% when learning to use a bench vise with immediate correction of movements. There was somewhat less increase in kinesthetic sensitivity in the group where there was continuous photic correction of movements (20%). In the control group, which work on an ordinary vise, the increase in kinesthetic sensitivity constituted about 6%. It was demonstrated that the increased sensitivity was transferred to another industrial operation (sawing a block of wood). While in the control group of subjects (who were trained under usual conditions, in work classes at school) the number of mistakes in sawing a standard block of wood decreased by 27%, in the experimental groups the decrease constituted 82% (in the group with immediate additional information) and 66% (in the group with continuous additional information).[42]

The obtained data confirm the opinion that adaptation to work actions is an active process, since it is related to heightened sensitivity of analyzers.

It is important to mention that the physiological processes of active adaptation to work do not amount solely to lowering of thresholds of excitability. This is indicated by the change in motor activity. The force applied by the subjects to file metal increased from 8 to 15 kg (right hand) as training progressed. Concurrently with increased force exerted by the right and left hands, the subjects presented a shorter period of development and completion of effort, and corresponding volleys of bioelectrical activity of the working muscles. The increase in maximum force with reduction of intervals of development and completion of this exertion corresponds to the process of concentration of muscular force.

Both the increase in kinesthetic sensitivity and concentration of muscular force are a manifestation of changes that occurred in the functional state of nerve centers in connection with summation of traces of excitation and active adaptation of the organism to the specified work activity. With decline of thresholds of kinesthesia in the nerve centers of the reflex

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system of the dynamic work stereotype for filing metal, there is an increase in excitability in the course of training. Concentration of muscular force and corresponding decrease in intervals of development of muscular exertion and periods of bioelectrical activity of working muscles are indicative of increased lability (or functional mobility) of the same nerve centers, the same functional reflex system.

Analysis of active adaptation revealed another important distinction of its physiological mechanism, which consists of the fact that the effect of additional information disappears at a certain stage of training. A young worker who has learned some work operation no longer requires additional information, and he performs the work movements without the help of light signals. What does a worker who has learned a skill use as a guideline for speedy and effective correction of his own movements? It can be assumed that an image of the required work action, to which real movements are compared, is formed in the human nervous system on the basis of trace consequences. When performing precision movements, the kinesthetic image of movement plays the leading role. A mechanic [fitter] perceives differences between expected and real kinesthetic stimuli, and immediately corrects development of motion. As was established in our studies of cyclic movements, a man receives and makes use of the main information, not only about deviations of the work trajectories from the appropriate model, but primarily about deviations of the second derivatives of motion, accelerations of parts of the body and tool.[43]

Signals of accelerations of parts of the body play the leading role in regulation of fine movements related to improving handwriting. Analysis of written exercises performed by elementary and senior grade school children convinces us that, at the first stages of learning to write, the student who has a visual image of letters shown in examples reproduces this image, comparing what he has written to the proper writing, in accordance with the visual image. The student corrects his motions in accordance with the principle of negative feedback, i.e., upon discovering a deviation from the example he makes a correction, he returns to the proper trajectory. Visual detection of distortion of the trajectory is possible only when the deviation is great enough, so that a written text acquires a typical appearance: each letter of the text is written separately, the trajectories of the letters are rendered in broken lines.

Higher grade school children, who join letters in words, present no signs of visual correction of motions according to mistakes. This change in handwriting is attributable to the fact that, as a result of exercise, the student began to make less use of visual correction and changed to kinesthetic correction of writing. He developed a kinesthetic image of the written letters and words, and now not only does not see in advance the proper rendition of letters and words, but programs the accelerations that change in time and that must be imparted to the writing tool when writing letters and words. Now the student does not correct the

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improperly traced trajectories of letters, but the wrong accelerations, from which the wrong velocity begins to develop and later, according to the laws of inertia, wrong elements in the trajectories. For this reason, visual correction of letter writing is usually unnoticeable in the written work of senior grade students. Correction of movements while writing occurs in accordance with a kinesthetic image, i.e., with the use of signals that travel to the central nervous system from muscle spindles (special receptors) in muscles that are sensitive to changes in tension. Thanks to the presence of a kinesthetic image of handwriting, the student can make rational use of force of inertia, kinetic energy of the moving masses of the hand and writing tool and, finally, he can use the law of concentration of muscular force. The use of these procedures facilitates and accelerates the writing process, reduces time spent on writing letters and words, makes it possible to relax muscles for a few instants when kinetic energy and force of inertia are used.

Figure 7 illustrates samples of writing by subjects differing in writing skill and the corresponding characteristics of bioelectrical activity of working muscles (interosseal and muscles of thenar eminence). This figure shows that muscular action currents have a definite tendency toward grouping into distinct groups, separated by periods of relative rest, in the case of better and more rhythmic writing. These are typical signs of concentration of muscular force.

When learning to file metal and working on a kinesthesiometer, similarly to learning the skill of writing, there is formation of a kinesthetic image of the proper movement, as a result of which it is no longer necessary to use additional visual (light) reference points.

The combined function of visual and kinesthetic images of the required work action and single reinforcement by reaching the planned result lead to combination of the special images into an integral image of the work action.

We have proved experimentally the reality of the integral image of work actions and work movements. The proof is based on the fact that there is representation in the human cerebral cortex of the traces of excitation which together constitute the material basis of the integral image of proper movements (S. A. Kosilov, A. I. Vasyutina, A. A. Rigina, 1970).

The examples we have discussed contain the experimentally substantiated answer to the question of which physiological processes are involved in refinement of work skills and increased precision of work actions. It can be stated with confidence that the physiological processes constituting the main content of active adaptation include heightened sensitivity of analyzers and lability (or functional mobility) of nerve centers, concentration of muscular force and neural processes (excitation and inhibition), formation and definition of the integral image of work actions. All these

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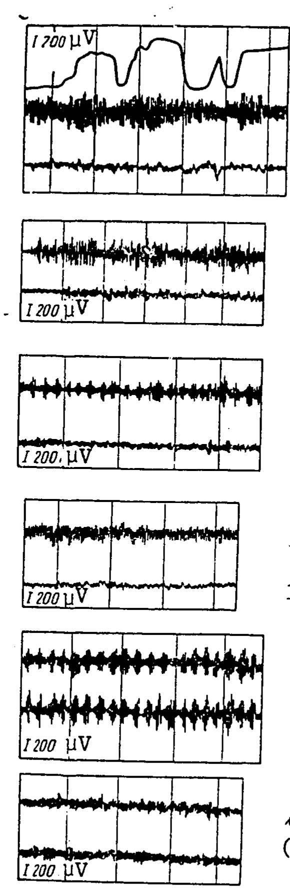
processes are instrumental in making movements more accurate, reducing expenditure of time and energy when performing movements, and they provide for effective assimilation of work skills.



"...приносит..." (subject B., first grade)

„ растения..." (subject Zh., 4th grade)

Криминалистика (subject S. Ye., 10th grade)

Криминалистика (subject I.T., 10th grade)

Криминалистика (subject G.B., adult)

Криминалистика (subject O.S., adult)

Figure 7.
Samples of writing by subjects of different ages and with different levels of assimilation of writing skill

The most important prerequisite for successful development of processes of active adaptation is summation of traces of nervous excitation with numerous repetitions of exercises under the influence of the work dominanta, which was formed when man was exposed to specific, socially determined factors. A number of social factors (desire to achieve like the leading workers, being invited by leading workers to join their work team, etc.) elicit specific reactions in the human body: formation in the nervous system of sites of heightened activity that direct man's activity toward the search for improving his performance. The presence of such foci of excitation is manifested by motivation of man's work behavior and behavior itself, which is characterized by goal-orientation, concentration, persistence in acquiring new work skills and, finally, development of physiological processes specific to the worker for active adaptation to work.

A specific personality trait, attention, without which work activity is impossible, develops under the influence of socially determined factors and formation of the work dominanta. Attention is a rather complex psychological phenomenon, which constitutes "a form of organization of mental activity of man manifested by its direction, concentration and relative stability." In the opinion of O. P. Shvetsov, the "physiological basis of concentration is reinforcement of

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excitations in the dominant focus asssociated with inhibition of all the rest of the cerebral cortex."[44] The direction of attention "also ensues from the conditions of formation of foci of optimum excitation and dominant foci."[45] O. P. Shvetsov substantiates this thesis by referring to a statement of A. A. Ukhtomskiy: "The dominant state is reinforcement and demonstration of existing correlation between central excitations.... In this sense, it expressly leads to execution in the form of a mechanism with specific direction of actions (with a specific vector) of the correlation of stimuli in centers, as yet little defined, which was prepared at directly preceding moments."[46]

The relative stability of attention also ensues from a property of the dominanta, its inertia. "The typical feature of the dominanta," A. A. Ukhtomskiy wrote, "is its inertia: one evoked, the dominanta is capable of stably remaining in centers for a certain time even after the stimulus that evoked it is removed."[47]

One can assess the intensity of the work dominanta by the intensity of its manifestations, in particular, stability and concentration of attention. These traits of attention can be tested in appropriate psychological experiments. Concentration of attention is evaluated by means of a test. It consists of the following. The subject is asked to strike out certain letters. The number of correctly crossed out letters within a specific period of time and number of mistakes are recorded.

The direct method of evaluating the intensity of the dominanta is based on its property of depressing, inhibiting so-called incidental reflexes, i.e., reflexes that are not consistent with the activity performed at a given time. For example, the subject has to maintain a static exertion constituting a large share of the maximum (about 80% of maximum exertion) and at this time a stimulus is delivered that elicits the patellar reflex. Measurement is taken of the reflex motion and bioelectrical response of the muscle (femoral rectus) that extends the leg at the knee. The obtained parameters are compared to the same parameters of the patellar reflex inherent in this subject when he is at rest. A reduction in values of parameters of the patellar reflex with the specified exertion can serve as a gage of intensity of the dominanta.[48]

The threshold of analyzer excitation is the quantitative gage of sensitivity.

The interval of development of biomechanical and bioelectrical processes during performance of elementary physiological work is the quantitative gage of lability (or functional mobility). Functional lability of the human motor system is characterized by reaction time or latency period of the motor reaction. Reaction time is the interval between delivery of stimulus and appearance of motor reaction. However, this parameter is not precise enough, since with different levels of functional lability there is a corresponding change in duration of elementary work of development and termination of excitation in response to the stimulus. Physiological

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elementary work does not end at the start of the motor reaction; it continues while performing the movement and during the gradual extinction of trace excitation. For this reason, the size of the full interval of development and termination of excitation related to a given motor reaction is a more accurate quantitative parameter of the level of lability of the motor system.

To determine the duration of the full interval of development and termination of excitation in the motor reaction an instrument is used, a programmed reflexometer (S. A. Kosilov, K. N. Markov, 1967), which is illustrated in Figure 8.[49] This instrument is based on the principle of paired stimuli. Pairs of identical stimuli (lights) are delivered at different intervals. In accordance with the instructions, the subject responds to each stimulus by depressing a telegraph key. Latency periods in response to these stimuli are recorded. If the latency period of the motor reaction is shorter after the second stimulus in a pair than after the first one, it means that trace excitation remaining after the first stimulus did not have time to equalize, and the effect of the second stimulus started against the background of an unterminated excitatory interval that developed after the first stimulus. In order to determine the duration of the interval of complete development and termination of excitation, one has to increase the interval between stimuli in a pair. The interval is increased until the latency periods are the same after the first and second stimuli. Under this condition, the interval between the two stimuli will equal the complete interval of development and extinction of excitation related to the motor reaction. The duration of the full interval of excitation will be the true quantitative expression of lability (or functional mobility) of the subject's motor system.

The quantitative gage of concentration of muscular force must express concurrently reduction of biomechanical and bioelectrical processes related to performance by man of elementary mechanical work, i.e., with development and termination of maximum velocities and accelerations of moving parts of the body, as well as increase and fuller demonstration of intervals between successive volleys of excitatory impulses.

One of the parameters of these phenomena is the generation and expenditure of kinetic energy when performing elementary movements (S. A. Kosilov, 1938, 1965, 1974).[50] As was established in studies of simple and complicated movements, concentration of muscular force makes it possible to create, within a short period of time, a reserve of kinetic energy of moving parts of the body in order to use this reserve in the segment of the work trajectory when direct use of muscular force is not advantageous and involves development of fatigue. The muscle is relieved for a certain time by the fact that previously stored kinetic energy is used on segments of the work trajectory where use of muscular force is not advantageous.

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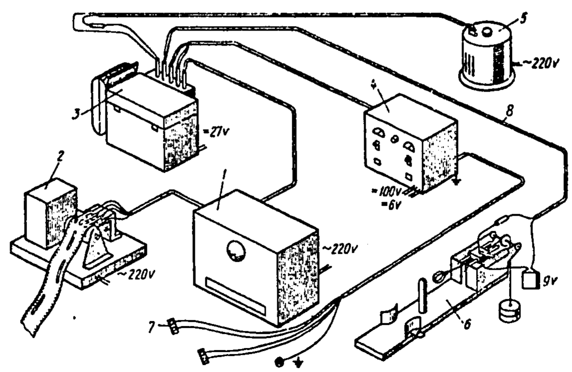

Figure 8. Device with programming reflexometer for determination of duration of period of extinction of traces of excitation

1) unit setting stimulus (light flash)
2) tape-feeding mechanism which evenly feeds tape with program for alternation of lamp flashing and off (the light is on when contacts are made through slits in the insulation tape)
3) oscillograph to record movements and bioelectric potentials of muscles
4) amplifier of bioelectric potentials of muscles
5) metronome used to set rhythm when trace processes are examined in the subject during the breaks between working at different paces
6) digital ergograph that the subject operates when reacting to flashes
7) electrodes for derivation of bioelectric potentials of muscles
8) wires to oscillograph for recording movements

Thus, the following could serve as quantitative parameters of level of development of concentration of muscular force (and neural processes): 1) magnitude of kinetic energy of moving parts of the body, which develops during achievement of maximum velocities; 2) duration of intervals and length of segments of work trajectory over which movement is maintained by accumulated kinetic energy, with relief and relaxation of muscles and corresponding decrease in bioelectric activity. Since kinetic energy is proportionate to the square of velocity of movement, maximum velocity of moving parts of the body could serve as an indicator of maximum kinetic energy.

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We used an attentiometer, an instrument developed by Ye. A. Mileryan (1966)[51] for quantitative evaluation of inclination for abilities to form integral images of work actions. There are signal lights, pointer instruments and aircraft model on the instrument panel. During the tests, the lamps light up, the instrument pointers move and the model changes its position. The subject must use the buttons and a lever to turn the light off, stop the pointer and return the model to normal position. The experimenter observes the subject's performance by means of counters of mistakes, tracking time meters and indicators of time spent on different tasks. There is a switch to set different speeds of presentation of the work program to the subject. After five work sessions, the attentiometer shows a decrease in number of erroneous actions and increase in signal tracking time. The coefficient of progress is determined from these data. Apparently, the level of this coefficient is related to accuracy of formation of integral images of action. We used the attentiometer to make an objective quantitative evaluation of inclinations for forming integral images of work actions in students at vocational and technical schools.[52]

In the case of highly developed inclinations for forming integral images of work actions, the subject working on an attentiometer demonstrates traits such as stability, concentration and orientation of behavior, which could be interpreted as a manifestation of attention from the psychological point of view.

The attentiometer makes it possible to evaluate quantitatively the innate inclinations of an individual for programming and correcting work actions, which occur in accordance with a law known in advance (algorithm). Programming, which is analogous to work with an attentiometer, is used in bench work, in particular, when working on metal-cutting lathes in machine building and some control consoles (for example, those of the subway). In addition to programming based on an unchanging law, industry uses variable control of a technological process in accordance with changes in the situation and, accordingly, variable programming and correction of work actions. In such cases, the worker must discern the possibility of significant disruption of a technological process on the basis of barely noticeable and rapidly developing changes in this process.

In order to prevent undesirable changes in the technological process he controls, the worker must mentally make the change from minor, rapidly developing changes in a process to the rate of these changes, then he must assess the scope of changes that could occur. The worker programs and corrects his own actions in accordance with signals referable to the second derivative about events that may occur, rather than signals about events that have occurred. He does not address his actions to the events themselves, but to the second derivative of possible events. Such a situation arises when controlling a technological process in the chemical industry and transportation. The described form of control is referable to control of secondary [second order] complexity.

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There must be a component of dual integration in the integral image of work actions in order to mentally shift from the second derivative of an event to a possible event. We evaluate quantitatively the innate inclination for development of the ability of dual integration and control of a technological process of second order complexity using an instrument we developed, the "imagometer" (D. P. Bukreyeva, S. A. Kosilov, 1976).[53]

The subject has to move the pointer of an indicating instrument, as quickly as possible, from the initial position to the position specified by instructions. He can do this rapidly if he imparts maximum acceleration to the pointer within a short segment of time, then an equally strong decelerating impulse (negative acceleration), and use a third movement to stop the pointer in the required position. By working with the potentiometer handle, the subject must turn it in one direction with the first movement, in the opposite direction with the second and return the handle to the initial position with a third movement. The time required from the start to stop of the pointer and accuracy of placing the pointer in the specified position serve as the quantitative parameter of accuracy of this work and a gage for evaluation of level of development of the innate inclination for control of technical systems of second order complexity.

One can use the above-described instruments for training of physiological processes of active adaptation. Such training has a definite advantage over traditional methods, which do not conform with the principles of modern scientific organization of labor. As we know, in the case of traditional industrial training, development of work skills is based on a scheme, in which the first element is instruction and demonstration of proper work actions. The next element is the trainee's attempt to perform the actions, with which he became acquainted by means of verbal explanations and demonstrations. The third element is the foreman's or instructor's evaluation of the results of the trainee's independent trials. If the trainee performs a given work operation incorrectly and obtains an unsatisfactory result, his mistakes are pointed out to him, the instructions are repeated, and he is asked to perform the action again. The trainee must determine himself what the mistake was and how it should be corrected.

Physiological analysis revealed that there could be an unsatisfactory result of a trainee's independent attempts due to difficulty in development of different processes of active adaptation. In the case of traditional industrial training, these processes are not in the instructors' field of vision, and they remain unknown to the trainee. There are no explanations about them in the instructions, since these processes cannot be consciously controlled, yet they are of decisive importance to acquiring a skill. Haphazard refinement of processes of active adaptation is a rather laborious and slowly developing process, which does not guarantee that the optimum variant of learning a work skill will be found. One of

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the tasks for scientific organization of labor is to shift from haphazard refinement of physiological processes of active adaptation to scientifically substantiated control thereof. Theory and practice of industrial physiology point the way for organization of scientifically substantiated control of processes of active adaptation.

The instructions to workers learning an occupation and undergoing advanced training must be given with due consideration of individual distinctions of physiological processes of active adaptation. The dynamics of these processes should be identified in each trainee, and exercises should be recommended for each trainee to aid in uniform development of active adaptation.

If a trainee or group of trainees have difficulties in enhancing the sensitivity of the kinesthetic analyzer, training with the use of additional guides [check, reference points] can be recommended.[54] This is corroborated by the discovery and use of the physiological effect of additional stimuli and guides to correct a learned movement.

Additional check points were first used to restore the work fitness of disabled veterans of the Great Patriotic War, after amputation of the upper extremities. It was very difficult for many of them to acquire the skill of opening the artificial hand of their prosthesis by means of a specially developed movement to drop the shoulder. Unsuccessful attempts to perform this movement had a very inhibitory effect on the patients, and they refused the prosthesis. Then a method was developed to teach this new movement by means of additional guides (S. A. Kosilov, M. S. Yusevich, T. I. Ivanova, 1953).[55] Miniature weights tied to strings going from the stump of the arm through a unit over the osseous process of the seventh cervical vertebra served as guides. When the patient tried to drop his shoulder by means of this simple device, the strings became taut and the weights rose. The height to which the weights rose corresponded to the traction* of the prosthesis connected to the mechanism of the artificial hand. To open the fist, traction of a specific magnitude was required, but one could not obtain the required traction without regular exercise. The patients lost interest in these exercises, not knowing the results thereof and not certain that they would help reach the required traction. But when the patients performed the exercises we developed, they could see their own backs through a system of mirrors, and they could observe the movements of the little weights in relation to a scale attached to the back. Movement of the weights informed them about performance of movements, mistakes made and increase in obtained traction. The existence of information about the movements they performed was instrumental in continuing the exercises to learn how to use the prostheses. In the future, such a method began to be used in pedagogics and physical culture.

*"vyborka tyagi" ["recovery thrust"?].

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Let us consider another example of purposeful, organized development of kinesthetic precision in students of vocational and technical schools.[56] We formed two groups of subjects in the experiment, each of which consisting of 20 people. One group was the experimental one and the other, the control. We studied the dynamics of formation of the professional skills of a lathe operator. In the experimental group, the subjects exercised to develop kinesthetic accuracy twice a week, on the days of industrial training, for 7-8 weeks. Analysis of the results revealed that the experimental group of subjects showed a significant improvement of accuracy of kinesthetic analysis as a result of exercise, as compared to the control group. Kinesthetic accuracy of the experimental group in the course of training on a Kosilov-Markov kinesthesiometer (Figure 9) increased by 17 arbitrary units, whereas in the control group it increased by 4 units. There was a 20-58% decrease in time of performance of the work operation in the former group, as compared to data obtained before training. In the control group, time of performance of the same operations decreased by 5-48% over the same period of time. In addition, there was more improvement in quality of processing the parts by the experimental group.

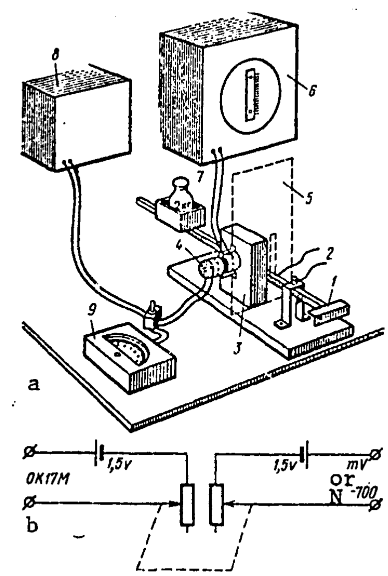

Figure 9. Diagram of kinesthesiometer of S. A. Kosilov and K. N. Markov

a) block diagram
b) basic circuit
1) stage for precision movement of lever with fingers
2) contacts to transmit movements to printing devices
3) redicer
4) potentiometer
5) screen to prevent visual monitoring of movements
6) oscilloscope for visual monitoring
7) contacts of wires to oscilloscope plates
8) N-700 oscillograph
9) pointer-equipped monitoring instrument

If trainees have difficulties in acquiring work skills because of low lability of the motor system, one should use special exercises directed toward increasing lability. For this purpose, we (S. A. Kosilov, K. N. Markov, 1967) developed an instrument, a concentrator (Figure 10).[57] This

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instrument has a round dial over which a pointer moves evenly. The subject is asked to depress a telegraph key when the pointer reaches the graduations specified in the instructions. By altering the rate of rotation of the pointer and number of graduations on the dial, to which the subject has to react with a movement, one can set different work paces for him.

Studies of individual lability (or functional mobility) were conducted at Moscow Vocational and Technical Schoool No 6.[58]

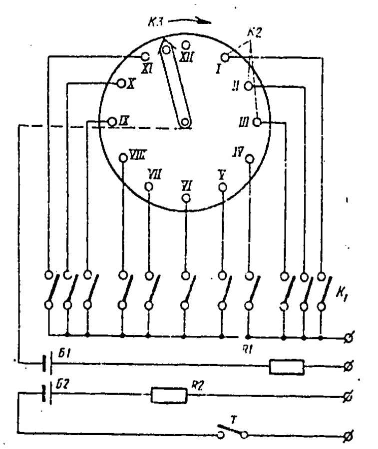

Figure 10.
Diagram of concentrator of motor reactions

K1) contacts to form program of alternation of stimuli
K2) contacts on dial
K3) contact on pointer
Б1, Б2) power sources to recording instrument (oscillograph)
R1, R2) resistances
T) telegraph key

A survey of 100 students learning the trade of lathe operator-metal worker revealed that they present wide differences in lability of the motor system. At the same time, it was known from previous studies (S. A. Kosilov, L. A. Leonova, N. S. Filina, 1972)[59] that acquiring a higher work rhythm, i.e., reaching a higher level of motor system lability, held an important place among the physiological processes that determine successful assimilation of this occupation. In order to improve the effectiveness of industrial training, it was necessary to accelerate processes of adaptation of the body to the work in those trainees whose lability remained below the average level of development.

It was assumed that in the course of training, "getting into the swing" and exercising, there is summation in the trainees of traces of nervous excitation leading to concentration of muscular force and neural processes, but this summation occurs at different rates in different individuals. It was of some interest to apply methods of training and developing lability of the motor system and thereby help the trainees who were behind.

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By gradually increasing the set frequency of movements, we created conditions for assimilating higher work paces. This involved the use of the physiological mechanism of summation of traces of excitation which remained after each successive movement.

An instrument, the programming reflexometer (S. A. Kosilov, K. N. Markov), as well as its power-operated version, the reflexometer-trace meter, developed by L. A. Leonova and V. Ya. Blinnikov, were used for quantitative evaluation of the level of functional lability of the trainees' motor system (113 people). The parameter of lability was assessed on the basis of the range of change in interval of appearance, development and extinction of the excitatory process related to the motor reaction to a stimulus specified in the instructions, lighting of a lamp. The subjects were divided into three groups, according to reaction time. If the reaction time leveledoff in the interval of up to 3 s, they were put in the first (labile) group, if this happened in the interval of up to 4-5 s they were classified in the second group (moderately labile) and with an interval of up to 6-8 s they were put in the third group (inert). Time studies were conducted on adolescents differing in degree of development of functional lability of their achievement in class assignments pertaining to metal work. An assignment involving a standard operation in working on a part, a check ring, was given to the students at the start of the school year and after 6-8 months of instruction. This operation consisted of several elements: turning the external cylinder, filing a groove, chamfering, etc. This operation was not too difficult for any of the subjects.

In analyzing the results of the time studies, we considered the following parameters: number of parts finished in the work day, quality of production, time required per part, dynamics of these parameters in time (in the course of a work day and the school year). The same parameters were used to make an objective evaluation of effectiveness of purposeful development of functional lability in the third group of subjects.

Table 5 lists data pertaining to natural change in functional lability of students in the course of a year's study (at the start and after 8 months of instruction). As can be seen from the data in this table, after 8 months of training at the vocational and technical school, there was the most appreciable change in level of functional lability in the second group. In this group, an increase in functional lability was observed in 17% of the students. In the third group, which had low lability, an increase was observed in only 6.5% after 6-8 months of training. On the average, the increase in functional lability in the course of the school year constituted 13% among students at the vocational and technical school.

We made a comparison of the effectiveness of formation of work skills in students with relatively high (first group) and low (third group) functional lability. The relevant data are listed in Table 6.

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Table 5. Changes in functional lability of the motor system

Groups of adolescents differing in level of lability	Number of adolescents in the groups		
	school year	At the end of school year: Increased lability	At the end of school year: No change
First group	14	--	14
Second group	53	9	44
Third group	46	3	43

Table 6. Changes in parameters of student performance as related to different levels of functional lability

Groups of students according to level of lability	Parts finished in work day: at start of school year	Parts finished in work day: at end of school year	Mean time per part, min: at start of school year	Mean time per part, min: at end of school year
First group	8	21	10.5±0.45	4.6±0.32
Third group	5	9	20.0±0.71	9.5±0.25

According to the data in Table 6, the students with greater lability presented high performance indicators. They produced more parts. This difference was observed both at the start and end of the school year. The rate of increase in efficacy of training (according to work productivity) was higher in the first group: the number of parts finished per day increased by 2.6 times in the first group and 1.8 times in the third. The time spent to finish one part was reduced by 2.3 times in the first group and by 2.1 times in the third. A comparison of the curves of dynamics of efficiency of trainees with different levels of functional lability in the course of a work day revealed the following distinctions.

At the early stage of training, the first group of students presented higher labor productivity (more finished parts) and faster adjustment to the work than the third group. After 8 months of training, the former presented less variability in time to finish a part. The third group showed signs of fatigue by the end of the work day, manifested by slowing of work actions (longer time spent on finishing the parts). Analysis of the obtained data revealed that the third group of students remained behind the first group throughout the school year with respect to labor productivity, and they spent twice as much time to finish a part at the end of the school year as compared to the first group. All this confirms the need to develop and use special measures in order to develop high functional lability of the motor system of students and young workers, since its natural growth in the course of traditional industrial training is not adequate.

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Exercising on a concentrator is one of the means of developing functional lability. In order to find a close to optimum regimen of exercise, we tested several possible variants, differing in number of sessions per week and in distribution during the week. We tested the following variants: 3 sessions per day, with two training periods a week, i.e., 6 sessions per week; 2 sessions per day 6 times a week, i.e., 12 sessions; 1 session per day 6 times a week, i.e., 6 sessions per week. Each exercise session lasted 10 min in all variants. After a 4-week trial, the first variant was found to be the most effective. With this variant, we observed maximum reduction of time of extinction of trace excitation. The corresponding increase in functional lability was stable, since it remained at the attained level 2 weeks after the exercise period. The participants in these exercises were students with a low level of functional lability (6-8 s). We conducted time studies of work time while performing a standard assignment (turning [working on] a check ring) before and after a 2-week period of exercise on the concentrator. The results of a subsequent test of effectiveness revealed that functional lability increased in all of the adolescents. Adolescents who were previously in the third group moved into the second one at the end of the exercise period. This was not observed among the untrained "inert" subjects (control group). Re-examination revealed that they remained in the group of inert students.

The time studies revealed that, after exercise on the concentrator, the students processed more parts per day and spent less time on the assignment. This was particularly distinct in some students at the beginning or end of the work day, i.e., during periods of maximum intensity of physiological functions. We failed to observe an increase in labor productivity over the same period of time among students who did not practice on the concentrator.

The results of this study indicate that one can organize, by means of physiologically substantiated exercise, rather rapid and effective summation of traces of excitation leading to an increase in functional lability of the motor system.

Improvement of man's work movements is governed by the specific law of concentration of muscular force. We succeeded in discovering this law and tracking manifestations thereof in numerous examples of simple, complicated work and natural movements, examining processes of exercise and assimilation of motor skills (S. A. Kosilov, 1938, 1965; D. P. Bukreyeva, S. A. Kosilov, A. P. Tambiyeva, 1975).[60] The significance of this special law of industrial physiology has been confirmed in the studies of other authors (K. S. Tochilov, 1951; Yu. V. Moykin, 1963; A. M. Novikov, 1973, and others) who were concerned with processes of improvement of different types of human motor activity.[61]

Application of the law of concentration of muscular force and neural processes to scientifically substantiated control of man's active adaptation to work may be one of the effective means of improving scientific organization of labor.

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How should one organize monitoring of independent accumulation of experience in a trainee, and what sort of help should there be for formation of the integral image of work actions? To answer this question, let us consider formation of the integral image of work actions in a trainee learning the occupation of metal worker [lathe operator]. When learning to work on machine tools [metal-cutting benches], operations that are learned consist of many elements (transitions). Difficulties in forming an integral image of work actions are manifested by disruption of order of elements of the operation (or transitions), presence of superfluous movements, stops and slowing down of work movements. In the process we studied, that of formation of initial skills in working on a lathe bench, 9th-grade students presented such phenomena while learning skills in checking measurements of parts that they worked on.[62]

Cinecyclographic studies of measuring movements involved in working on the same part and on the same lathe by a 9th grade student (average achiever) and a lathe operator in the 5th skill-category revealed differences in work methods of the two subjects. The measuring movements of the student constituted 12.5 s, while those of the skilled worker lasted 4.2 s, i.e., one-third of the time spent by the student. The student takes the measuring tool (slide gage) lying to his left on a stand immediately after performing the preceding actions (cylindrical turning) in order to check the diameter of the part, right after the lathe power feed stops. But he forgets that he must stop the rotation of the lathe shaft and move the cutter away from the part before taking the gage in his hand. He does all this later, after he places the branches of the compass on the required graduation. Having stopped the lathe and moved the cutter away, the student again places the gage on the required graduation. The first and seemingly most probable explanation for such flawed actions is the student's poor knowledge of the instructions. However, a check revealed that the student knew well the repeated (at the beginning of each work lesson) instructions and could repeat them without mistakes. When then, knowing the content of the instructions, did the student make mistakes in performing the actions specified in the instructions?

This happened because, as he moved from one action to another, the student had to be guided not only by conscious and verbally formulated concepts and conceptions, but by the directly perceived stimulation of nerve endings of the motor analyzer. The excitatory impulses traveling continuously from the nerve endings to the centers of the motor analyzer have to be compared to the traces of excitation remaining from previously performed correct work actions. These excitatory traces must form a single functional whole with the excitatory traces remaining from the teacher's instructions, i.e., they must form the integral image. For this purpose, there must be functional combination of excitatory traces from stimuli of the second signaling system and stimuli of the first signaling system. A method that could be applied in practice was developed for such functional unification of trace processes occurring in the two different signaling systems of reflection of reality.

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With this method, the student must perform exercises, repeating verbally the instructions while performing the actions they specify after listening to the instructions, learning them and answering test questions, before undertaking the task. In this case, our physiologically substantiated instructions consisted of having the student, while performing all of the work movements required for a given operation in their proper order, explain their production meaning. A test of such physiologically substantiated instructions in a school workshop class revealed that this can accelerate learning of work operations on a lathe by 20-40% (20% in good achievers and 40% in average achievers).

Analysis of these examples confirms that the existing system of work and industrial training can be refined by implementing recommendations, which were developed on the basis of physiological studies of student exercises and education.

It is imperative to include in physiologically substantiated scientific organization of labor and in the system of vocational and industrial education the physiological principles of the dynamic work stereotype, integral image of work movements and concentration of muscular force and neural processes.

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CHAPTER 5. PHYSIOLOGICAL FEATURES OF MANUAL AND MECHANIZED LABOR

The psychophysiological patterns of development of the dynamic work stereotype, work dominanta, integral image of work actions and assimilation of rhythm discussed above are common to workers in different professions. However, to solve problems of organization of labor, it is imperative to take into comprehensive consideration not only general patterns, but the distinctions of physiological processes in representatives of different occupations.

All labor is purposeful and work movements are used in any work to reach a set goal. But, the goal of labor and nature of work movements vary over a wide range, depending on the distinctions of the occupation, properties of the end product of labor and technological process. The range of changes in various forms of work goals may be very broad, from movement of weights to issuance of responsible orders and instructions to large groups. There is also wide variation of work movements, from lifting heavy objects to the movements needed to write and speak.

Key Physiological Functions in Different Forms of Work

According to the foregoing, the dynamic work stereotype is basically a system of interacting functions with unequal elements.

In all forms of labor there are physiological functions that are decisive to acquisition of work skills and to maintenance of efficiency on a high level, or key functions. Changes in key functions during work under normal conditions reflect a change in physiological processes in conformity with the specific production task. Subordination of work behavior and physiological functions to the goal of labor is manifested by the non-uniform increase in intensity of different functions: maximum increase in intensity is inherent in key functions.

In physiological studies of heavy physical labor, attention is given primarily to self-regulation of metabolic processes, cardiovascular and respiratory activity, since expressly these processes determine the possible level of increase in intensity and duration of labor, and degree of stability of the dynamic work stereotype. In the case of moderately heavy manual labor, metabolic and respiratory-circulatory processes are

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no longer decisive or limiting factors. Work, for the performance of which precise coordination of movements and planning of complex work operations are required, is related to increased intensity of neural processes involved in programming and correction of motor acts, which is reflected, for example, by changes in the oculomotor reaction. When performing various types of mental labor, formation and maintenance of concentrated attention, an integral complex system of trace processes at the basis of impression in memory of knowledge, perception and processing of new information play the leading role.

In each form of labor, the key physiological functions must be manifested in a specific range of intensity. Optimum adaptation to work of the key physiological functions is observed in different sectors of industry under normal (or close to normal) environmental conditions in the second and third hours of the work shift, i.e., after the period of "getting into the swing" of the work. Functional changes were recorded directly at the work places for adult workers.

Table 7 lists five cycles of regulation of physiological processes that are typical of five main categories of labor: heavy physical labor, moderately heavy manual labor, work of lathe operators, high precision work involving monitoring and measuring operations, mental labor. For each work category, examples are given of the work and characteristics of key physiological functions that can be used to assess the level of intensity of physiological processes (maximum, normal, or average, and minimum).

Key Cycle of Self-Regulation During Physical Labor

When performing work that requires significant muscular exertion, adaptation of the body consists of increased expenditure of energy. The magnitude of expended energy is indicative of the intensity of physiological processes that occur chiefly in muscle tissue.

The daily expenditure of energy in representatives of different occupations depends on the amount of mechanical work a man performs. Hence, one can determine the desirable physical load norm according to the quantitative parameter of expended energy.

Table 7 shows that energy expenditure should constitute 240 kcal/h with optimum adaptation to heavy physical labor. Knowing the energy cost of each work operation and the mean norm of energy expended per hour of work, we can calculate the number of operations that must be performed in one hour and per work shift.

Energy expenditure can be determined by indirect calorimetry (exchange of gases). For this purpose, a mask with valves is put on the subject. Air enters the lungs through one of the valves and exhaled air passes through

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the other valve into a rubberized bag attached to the worker's shoulders. Exhaled air that is thus selected is examined for oxygen and carbon dioxide content. From the amount of oxygen taken up within a given segment of time, determination is made of the calories extracted from nutrients oxidized in this time.

Numerous studies of gas exchange in workers of different occupations, which were conducted by industrial physiologists of different countries, made it possible to obtain parameters of energy expenditure during performance of widely used manual labor operations. On the basis of these data, one can settle the question of optimization of key physiological function during performance of a specific type of work.

By examining energy consumption during different types of physical labor, one can approximately evaluate its intensity. The category of light work includes the forms of muscular activity, with which energy consumption increases by no more than 2-2.5 times, as compared to basal metabolism. Moderately heavy labor refers to work, during which energy consumption increases by 3-4 times, as compared to basal metabolism. Labor requiring even greater consumption of energy is classified as heavy.

Energy consumption should not be considered an unequivocal and exhaustive characteristic of intensity (tiresomeness) of different types of work, since tiresomeness does not depend only on the level of energy expended, but on magnitude of static tension, distribution of load on working muscle groups. The main cause of fatigue is the change in functional state of neurons, which disrupts the dynamic work stereotype. If relatively weak muscle groups are mainly involved in the work, as is often the case when assembling small mechanisms, working on a conveyer and other similar operations, fatigue occurs rapidly, in spite of the relatively minor expenditure of energy.

Adaptation of Respiratory and Circulatory Functions to Physical Labor

In view of the fact that there is an increase in intensity of oxidative processes in a man engaged in physical labor, a need arises for increased influx of oxygen to the site of its utilization, i.e., muscles. This need is met by the coordinated function of the respiratory and cardiovascular systems.

When switching from rest to physical labor, there is an increase in respiratory rate; respiration becomes deeper, and this leads to an increase in pulmonary ventilation, i.e., total amount of air passing through the lungs in 1 minute.

At rest, an adult man performs 14-16 respiratory excursions per minute. If about 0.5 ℓ air passes through the lungs in each excursion, pulmonary ventilation at rest will constitute 7-8 ℓ. During heavy physical labor, pulmonary ventilation may constitute up to 40-60 ℓ/min.

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Table 7. Indicators of adaptation of key physiological functions to some forms of industrial labor

No	Category of labor and predominant cycle of self-regulation of physiological processes	Examples of work	Characteristics of key physiological functions: Parameters of key physiological functions	Values of parameters: minimum	maximum	mean
1	Heavy physical labor involving great muscular exertion and considerable energy (self-regulation of metabolic processes)	Foundry, loading work, etc.	Consumption of energy, increased circulation (heart rate)	100 kcal/h 60-100 beats/min	500 kcal/h* 125-150 beats/min	240 kcal/h 100-125 beats/min
2	Moderately heavy physical labor involving simple, similar movements (development of reflex in cerebral cortex to time, spinal and cerebellar cycles of regulation of even movements)	Work on assembly conveyers in instrument making and light industry	Rate of oculomotor reaction, lability of muscles and visual analyzer, variability of velocity of work actions	430 m/s 40 Hz 10%	500 m/s 75 Hz 20%	465 m/s 60 Hz 15%
3	Cold treatment of metal, manual and mechanized labor (cortical regulation of motor actions)	Metal work	Concentration of nervous processes and muscular force: striking speed duration of impact of cutting metal	8.6 m/s 0.18 s	9.3 m/s 0.23 s	9 m/s 0.20 s
		Work on metal-cutting lathes	Concentration of nervous processes and muscular force (time of development of volley of bioelectric oscillations in brachial biceps--BB and carpal flexor--CF in "end trimming")	0.77 s BB 0.93 s CF	2.82 s BB 3.29 s CF	1.8 s BB 2.1 s CF

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Table 7 (continued)

4 High-precision work involving monitoring & measuring operations (cortical cycle of self-regulation of analyzers	Work with optical instruments (microscopes, binocular lenses)	Precision of visual analysis (decreased in relation to initial level)	15%	78%	47%
		Lability of visual system (decreased in relation to initial level)	22%	58%	44%
5 Mental labor (cortical cycles of control of mental actions)	Work with computers	Adherence to law of force in dynamics of higher nervous activity (no signs of hypnotic phases of protective inhibition)	0	0	0
	Operator work in aviation industr.	Lability of visual analyzer	30 Hz		
	Operator work at airports	Blood sugar level	to 176 mg%	to 198 mg%	to 189 mg%
	Work of plant designers & technologists	Functional lability of nervous processes in cerebral cortex:			
		Time of extinction of excitation	--	--	to 8 s
		Time of extinct. after differentiation excit.	--	--	to 20 s
		Programming & correction of complex behavior in anterior frontal cortex (coefficient of activity)	7%	15%	12%

*This level of energy consumption can be maintained continuously for only a few minutes.

Note: This table was compiled on the basis of literature sources. These data are contained in the following books:

Lehman, Gunther "Practical Industrial Physiology," translated from German, Moscow, Meditsina, 1967 (category 1)

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Note to Table 7 (continued):

Vinogradov, M. I. "Physiology of Work Processes," Leningrad, Meditsina, 1966 (category 1)
Gritsevskiy, M. A. "Work and Rest Schedule for Different Types of Conveyers," in "Rezhim truda i otdykha pri rabote na konveyernykh liniyakh" [Work and Rest Schedule for Working on Conveyer lines], Izd. State Committee for Labor and Wages under the USSR Council of Ministers, Moscow, 1959, p 90 (category 2)
Zolina, Z. M. "Physiological Bases for Rational Organization of Work on Conveyers," Moscow, Meditsina, 1967, p 145 (category 2)
Kosilov, S. A. "Physiological Bases of Scientific Organization of Labor," p 162 (category 3)
Tochilov, K. S. "Physiological Study of Motor Skill Formation During Industrial Training," in "Voprosy fiziologii truda" [Problems of Industrial Physiology], Moscow, Medgiz, 1957, p 194 (category 3)
Filina, N. S. "Distinctions of Formation of Professional Motor Skill in Students at Early Stages of Training," in "Novyye issledovaniya po vozrastnoy fiziologii" [New Research on Age-Related Physiology], Moscow, Pedagogika, No 2, 1977, p 109 (category 3)
Moykin, Yu. V. "Physiological Substantiation of Rationality of Progressive Work Operations of Lathe Operators," GIGIYENA I SANITARIYA [Hygiene and Sanitation], No 4, 1960, p 35 (category 3)
Konovalova, A. V. "Studies of Efficiency of Stereoscope Workers, and Physiological Substantiation of Ameliorative Measures," author abstract of dissertation in defense of academic degree of candidate of medical sciences, Moscow, 1956 (category 4)
Vol'khina, T. P.; Pastukhina, G. I.; and Trofimova, L. V. "Physiological Changes in the Body During Intensive 'Visual' Work," in "Materialy 4-y nauchnoy konferentsii po fiziologii truda" [Proceedings of 4th Scientific Conference on Industrial Physiology], Leningrad, Izd-vo LGU [Leningrad State University], 1963, p 74 (category 4)
Pavlova, T. N. "Changes in Higher Nervous Activity of Computer Operators in the Course of a Work Day," ZHURNAL VYSSHEY NERVNOY DEYATEL'NOSTI [Journal of Higher Nervous Activity], Vol 4, No 2, 1954, p 166; "Physiological Substantiation of Work Schedule for Employees in the Mechanized Accounting System," in "Voprosy fiziologii truda," Moscow, Medgiz, 1957, p 150 (category 5)
Kikolov, A. I. "Mental and Emotional Tension at Control Consoles," Moscow, Meditsina, 1967 (category 5)
Kosilov, S. A. "Essays on Industrial Physiology," p 311
Aminev, G. A., et al. "Effect of Exercise on Functional Activity of the Cerebral Cortex of Students in a State of Mental Fatigue," in "Materialy 6-y respublik. nauchno-teoreticheskoy konferentsii po voprosam fizicheskogo vospitaniya i sporta sredi detey i molodezhi" [Proceedings of 6th Uzbek Scientific and Theoretical Conference on Physical Education and Sports Among Children and Young People], Tashkent, Meditsina, Uzbek SSR, 1977, p 18 (category 5)

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A man with well-conditioned respiratory muscles and large vital capacity presents an increase in pulmonary ventilation with significant physical loads, the increase being referable chiefly to depth of inspiration and expiration with relatively minor involvement of respiration. An unconditioned individual increases pulmonary ventilation chiefly by means of faster respiratory excursions.

However, the influx of oxygen to muscles is not restricted by pulmonary ventilation, but by the physiological mechanism of transmission of oxygen from the lungs to muscle tissue. This transfer occurs through blood which, because of heart function, is in continuous movement in the systemic and pulmonary circulation. In the pulmonary circulation system, the blood that passes through capillaries of the lungs comes in contact with air that is in the small alveoli of which the lungs are made. There is exchange of gaseous components between the blood of capillaries and alveolar air. In accordance with the law of diffusion, carbon dioxide passes from blood in the direction of lower concentration in the alveoli, while oxygen passes from the alveoli into blood, in accordance with the same law. Oxygenated blood, free of excessive carbon dioxide, travels over the pulmonary veins to the heart, enters the left atrium, where the pulmonary circulatory system ends. Then the blood goes to the left ventricle, from which its new cycle begins, i.e., movement in systemic circulation. Blood brings nutrients and oxygen over the systemic circulation to muscles and other tissues, and removes metabolic products, including carbon dioxide.

Adaptation of the circulatory system to physical labor consists of an increase in blood follow corresponding to intensity of work and, accordingly, to the requirements of tissues with regard to oxygen and nutrients. Minute blood volume is the quantitative gage of blood flow, i.e., the amount of blood that passes through the cross section of the circulatory system in 1 minute. According to the physical laws of movement of fluid in a closed system, an increase in minute volume can be obtained, in the first place, by creating a greater pressure gradient under which blood flows in arteries at the start of the cycle and in veins at the end; in the second place, this can be obtained by reducing resistance in muscular capillaries. The first condition is met by intensification of heart function, higher heart rate, and the second by dilatation of capillaries.

Motor Activity as a Need of the Healthy Body

Motor activity is one of the important prerequisites for normal existence and development of man. A decrease in motor activity below a specific minimum has an adverse effect on human health, and the same applies to excessive increase in intensity of physical labor. The latter causes depletion of the store of energy-containing substances in the body, due to impossibility of total compensation of excessive expenditure of energy received with the food taken daily.

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During physical labor, with optimum graduation of the work load, a working man develops some positive traits: muscular force and endurance, speed and rhythm of movements, dexterity. In addition, in the case of a regular optimum physical load, there is an increase in the body's resistance to various deleterious factors, in particular, diverse infections. Animal experiments have proven that an optimum physical load increases resistance to hypoxia (shortage of oxygen), toxic agents, penetrating radiation, overheating and overcooling.

While an optimum physical load is a factor in strengthening and preserving health, as well as increasing efficiency, when the physical load decreases below the average level (hypodynamia) it must be considered as a factor that is deleterious to human work and vital functions.

Referring to statistical and experimental data, physiologists indicate that "the amount of energy expended directly on muscular work should constitute a mean of at least 1200-1300 kcal per day for normal function of the body. For this reason, individuals who are not engaged in physical labor and who expend less energy on muscular activity must exercise."[63]

Key Cycle of Self-Regulation During Work Requiring Numerous Repetitions of Light, Simple and Monotonous Movements (Work on Conveyers and Assembly Lines)

An increase in labor productivity on conveyers and assembly lines occurs as a result of profound separation of labor, continuity of the production process and rhythmic work actions. Separation of labor makes it possible to achieve a high degree of perfection of individual, relatively simple work actions, into which the production process is broken down. The continuity of the production process (parts pass from one operation to the next without accumulation and without waiting for collection of a batch, as is the case when parts are transferred from one shop to another) leads to a substantial saving of time. Rhythmic work actions cause a change in physiological processes in workers and development of a special reflex, which was named the "time reflex." The time reflex during motor activity of man is manifested when movements required of him are performed at a specific pace. For example, one can organize work on a manual ergometer in such a manner as to have the subject lift and drop a weight in time with a metronome. At the start of this work, the subject waits for the signal, the metronome beat. He starts to lift the weight only after hearing the metronome. Having lifted and dropped the weight, before making the next movement the worker again waits for the metronome beat. He continues to work in this fashion until he develops a time reflex, i.e., the subject begins the next movement without any signal, at an interval that equals the period between two signals. Thanks to the time reflex, he is able to perform the work actions without fixing his attention on numerous extraneous signals, and this facilitates the work considerably.

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Work is alleviated and productivity increases in the case of a rhythmic production process as a result also of rationally organized summation of excitatory traces. It has been proven experimentally that the trace of excitation from a single exertion persists for 45 min when performing considerable muscular work and occasionally longer; but in the case of light movements, for example, depressing a button, it lasts about 8 s.

A distinction is made between several stages of extinction of a trace and equalization of excitation. The first, short stage is called the absolute refractory stage, or refractory period. The absolute refractory period is characterized by a very high level of excitation, because of which any additional stimulation at this time does not elicit a reaction, since the sum of existing excitation and newly delivered stimulation produces excessive excitation (pessimum), to which the excited living substrate does not response with its inherent physiological reaction.

The period following the absolute relative refractory one is characterized by the fact that mild stimuli can elicit a mild reaction in living tissue, while intensive ones lead to the pessimum.

Then follows the exaltation phase, which begins about 20 s after the first exertion in the case of great muscular exertions. It is manifested by appearance of heightened excitation, as compared to its initial level, in response to a stimulus of the same force. With this reaction, along with development of activity inherent in a given living tissue, there are some changes in functional state of tissue, an increase in excitability and lability, or functional mobility. Let us recall that lability, or functional mobility, is characterized by the rate of appearance, development and termination of excitatory processes, i.e., the time during which tissues or cells are capable of the excitatory process (wave of excitation). Lability is determined by the maximum number of excitatory waves that living tissue can reproduce per unit time.

The reaction of excitable tissue is negligible to stimuli of moderate force and frequency.[64] With increase in force and frequency of a stimulus (electricity is used in special experiments), the reaction gradually increases to the optimum level. Further increase in force and frequency of stimuli leads to a pessimum, and there is a decrease in excitability and lability of tissue. With stimuli of excessive force and frequency, as well as very long summation of traces of nervous excitation which, as it accumulates under the influence of stimuli delivered to tissue, changes into inhibition of the parabiotic type. The change from excitation to inhibition under the influence of excessively strong and frequent stimuli is the general law of vital functions of excitable cells and tissues, the law of parabiosis.

When working on assembly lines and conveyers, development of the time reflex, law of parabiosis, summation of traces of excitation, increase and decrease

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in excitability and lability are manifested by changes in functional state of analyzers and man's motor system.

A rationally formed time reflex helps establish a stable work rhythm, i.e., it reduces variability of work operation time and intervals between operations.

Rationally organized summation of traces of nervous excitation consists of the fact that each successive stimulus at the start of a work operation or work action occurs at the phase of exaltation of the excitatory trace remaining from the preceding operation or preceding work action, or element of action (if the operation is complex). There must be a stable level of trace excitation at the time of a new stimulus throughout the work shift. This is associated with achievement and prolonged maintenance of a high level of lability of the nervous system, which is needed for the performance of work operations at the speed set by the conveyer.

Unrationally organized summation of traces of nervous excitation leads to development of a pessimum state, impairment of the reflex system of the dynamic work stereotype, diminished efficiency and labor productivity.

The pessimum state that is induced by summation of traces of excitation from monotonous activity develops gradually. The individual usually continues to work against the background of diminished efficiency, using compensatory measures. One of these measures is intensification of stimuli delivered to working muscles from nerve centers. More intensive stimulation reaches the working muscles and extends (irradiates) over the the entire muscular system, involving muscles and muscle groups that not related to a given activity in this work. Irradiating stimulation influences the viscera and heart, as a result of which one observes an increase in the heart rate. Superfluous movements and a rapid heart rate are indicative of difficulties of working, which are overcome by increasing the intensity of nervous activity. Such excessive tension is dangerous to cells of the cerebral cortex, since it can elicit irreversible exhaustion in them. There is a physiological mechanism in the cerebral cortex that protects its cells from exhaustion and stress, protective inhibition. It is triggered as the last defense against impending stress. The sensation of monotony, boredom, sleepiness and lack of interest in the work are the external manifestations of protective inhibition.

The steps instituted to refine organization of work on conveyers, which took into consideration the physiological distinctions of man, have yielded a beneficial effect. For example, on those sections of production where an optimum work rhythm was introduced and adhered to in organizing work on a conveyer, for proper use of key physiological functions--time reflex and summation of traces of nervous excitation--the workers spent less time and energy on performing operations, there was improved accuracy of movements and visual perception.[65]

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It is imperative to make a precise quantitative evaluation of key physiological functions of workers in order to develop measures to refine work processes on conveyers and assembly lines. At the present time, industrial physiologists have developed the appropriate methods and equipment, which is used to test key functions of workers, and this permits purposeful change in these functions.

In order to determine the accuracy of manifestation of the time reflex, one can use the statistical parameters of rhythm of work operations (coefficient of variation V of duration of operations), mean duration of work operations for every 30 min of work during the work shift (M) and standard deviation (σ). These parameters are calculated on the basis of results of time studies, during which the time of start and end of work operations is recorded (using a stopwatch).

During the first hour of work and at the start of the second hour one observes a decrease in values of M and V, while a gradual increase thereof is usually observed in the fourth hour of the work shift. A decrease of M signifies faster perception of stimuli and performance of actions corresponding to the system of reflexes of the dynamic work stereotype. A decrease of V is indicative of a more accurate rhythm of performance of successive work operations.

M. A. Gritsevskiy established that the decrease of V constitutes about 40% (from 22 to 12%) after introduction of a rational work and rest schedule, from the physiological point of view, during work on conveyers requiring significant tension of the muscular system (performance of actions: to remove object of work from conveyer, move it, place it on the conveyer, with a part weighing 8.5 kg). When work involves less muscular exertion, coefficient V underwent analogous changes while "getting into the swing" (from 20% in the first 30 min of working to 10% in the fourth half-hour). In the case of negligible muscular exertion, the coefficient also dropped by 20-40% in the first two hours of work.[66] For this reason, we can arbitrarily consider that the rhythm should change within expressly this range (accuracy of manifestation of time reflex), in the case of a physiologically normal schedule, when working on a conveyer and performing relatively simple and brief work operations.

The variability of parameters of adaptation of key physiological functions reflects the accuracy of regulation and self-regulation of the dynamic work stereotype. It is known that, in developing self-regulating systems, much attention is given to achievement of as little as possible deviation of the regulated parameter from the set value. With regard to this parameter, a distinction is made between stable and unstable self-regulating systems. Thanks to the time reflex and summation of excitatory traces, a self-regulating system of the dynamic work stereotype may change to a state of high stability, which is typical of optimum adaptation of the body to work activity.

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The rationality of organization of summation of traces of nervous excitation is determined by means of parameters of bioelectric potentials (action currents of functional muscles), physiological lability or functional mobility, of the motor and visual analyzers, and speed of sensorimotor reactions. Each of these parameters reflects certain aspects of complex physiological processes that occur in the work process.

Analysis of bioelectric activity of muscles yields the most valuable information about the physiological mechanism of man's adaptation to work and maintenance of the dynamic work stereotype. Bioelectrical activity is the most important material process in the complex physiological reaction of excitation, without which it is impossible to develop excitation in muscle and nerve tissue. One can assess the magnitude of nervous impulses traveling from the spinal cord and brain to muscles, which are the effector systems of motor activity, from the nature of bioelectrical activity. Nervous impulses come to muscles in groups, the frequency and duration of impulses may vary. Analysis of bioelectrical activity of muscles demonstrates the most accurately the presence of summation of excitatory traces, concentration of muscular force and nervous processes.

It is desirable to record action currents of muscles throughout the work shift in order to study changes in physiological processes and functional state of the human body while working on a conveyer. Because of the existing methodological difficulties, few such length studies on the job have been conducted thus far; but they are very important to definition of theory of formation of the dynamic work stereotype and neurogenic theory of dynamics of efficiency.

In order to record muscular action currents, electrodes are attached to the tested muscles with a bandage or collodium. They have the appearance of plastic cups (1.5 cm in diameter), which have a metal protrusion on their internal surface through which electric contact is made. Several layers of gauze saturated in saline (0.9-1% NaCl) are placed between the protrusion and skin surface (after rubbing it with pumice to remove the top layer of epidermis and swabbing the surface with alcohol to remove fat). The electrodes are attached to the muscle (skin surface over the muscle) in pairs, at distances of 1-2 cm from one another. The action currents that appear during muscular contract travel from the electrodes, over wires, to an amplifier, then an oscillograph, where they are recorded on moving paper photographically or by means of an ink-writing instrument.

Valuable information about the dynamics of efficiency during moderately heavy labor and with a load on limited muscle groups can be obtained by recording muscular action currents during work. Particularly valuable information is obtained from recording the action currents together with

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a synchronous tracing of bioelectric potentials of the heart (electrocardiogram). From these data, one can assess the level of nervous and muscular tension, extent of dissemination of excitation to vegetative organs, level of refinement of regulation of muscular activity and assimilation of optimum work rhythm during the hours of "getting into the swing" of work. Assimilation of optimum work pace, which is faster than the first operations, and appropriate nervous regulation are characterized by the following on electromyograms (tape with tracing of action currents of muscles): duration of periods filled with groups of large oscillation; duration of periods of relatively weak oscillations and "noise," mean amplitude of action currents during periods of groups of large oscillations. From these data one can determine overall bioelectrical activity and its magnitude per unit time.

A decrease in duration of tetanus means that there is concentration of physiological activity of muscles and nerve centers in a shorter period of time. Such a change in function of the motor system enables a worker to select more accurately the time and point of the work trajectory, at which to apply maximum force and reach the most useful effect of the operation.

An increase in mean amplitude of action currents indicates that, with optimum adaptation to working conditions, there are rapid and accurate muscular contractions, which are insignificantly corrected by additional, small groups of nervous impulses. These changes in regulation and self-regulation of physiological processes are a unique form of increase in functional mobility, or lability, of man's muscular system, as a result of summation of excitatory traces and reinforcement of the dynamic work stereotype by achievement of a result. Increased lability is manifested by a reduction of periods of development and termination of excitation corresponding to a single muscular contraction, or tetanus.

N. Ye. Vvedenskiy proposed that the maximum number of stimuli that a myoneural preparation could perceive per second and to which it could react adequately without distorting the rhythm as a gage of lability in the living model he studied, a myoneural preparation (surviving muscle and nerve of a frog).

A method has been developed in industrial physiology to determine lability in man, in which this methodological principle of N. Ye. Vvedenskiy is applied. For example, determination is made of level of lability of the human visual system. Intermittent square wave current not exceeding 7-8 V is passed in the stimulating circuit by means of an electric stimulator, an instrument that permits delivery to a tested organ of rhythmic stimuli (pulsating electric current). Nonpolarizing electrodes are applied to the skin in the region of the temporal fossa, near the optic nerve. At first, current of the lowest frequency (no more than 1 Hz) and lowest voltage (about 1.5-2 V) is delivered through the electrodes. Determination is made of the threshold of stimulation of the optic nerve

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with minimum frequency of pulsating square-wave current. Then the voltage is gradually raised, leaving the frequency unchanged. When the stimulating current reaches threshold voltage, the subject experiences the sensation of a light flash (phosphene) with each pulse of current.

After the voltage reaches the threshold level (which is determined from the verbal report of the subject), it is increased by 1.5 times, and frequency of current pulsation is gradually increased. At a certain frequency, the subject no longer has the sensation of phosphene. The frequency of stimulating current reached at this time is the gage of lability of the visual system. In a normally proceeding work process, there is 10-15% increase in lability of the visual system in the second hour of the shift of a worker on conveyer assembly or other simple work.

Electrostimulators are used to determine the lability of the motor system of man, which deliver rhythmic stimuli at frequencies of 1 to 500 Hz, the voltage changing from threshold level to 10 V. The stimulating electrodes are applied to a motor point, i.e., where a nerve enters the muscle. As the current frequency increases (at voltage that is 1.5 times the threshold level), the mechanical reaction of the stimulated muscle is recorded on the surface of a revolving drum (kymograph). As the frequency increases, at this voltage, at first notched tetanus is recorded then complete tetanus; with further increase in frequency, an optimum is reached, at which the contraction presents maximum amplitude; with increase in frequency beyond the optimum level, muscular contraction diminishes and could reach a minimum, which is inherent in the pessimum state. There are qualitative features inherent in each of these functional states, which develop successively with increase in frequency of stimulation.

In the second hour of work (by the time the worker is completely "in the swing"), the quantitative parameters of functional state of the tested muscle rise.

In studies of the effect of increased frequency of stimulating current, it is imperative to bear in mind that the duration of each pulse of current should not exceed half the entire period of delivery of the stimulus. For example, at a frequency of 500 Hz, the complete duration of stimulation is 0.002 s. Consequently, the duration of a pulse should not exceed 0.001 s in this case.

Changes in functional state of excitable tissues and cells are also reflected by the speed of sensorimotor reactions. While the level of lability is indicative of the length of the time period during which excitation arises and has time to go through the stage of extinction of the trace, after which the next complete excitation is possible, the speed of the sensorimotor reaction gives us the length of time from the moment of stimulation to the start of the motor response.

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A reflexometer is used to determine the speed of the visual-motor reaction. This instrument includes a screen, from which light signals are delivered, a console with buttons to turn on the lights on the screen, a button or key that the subject uses to turn off the stopwatch that measures the time, in thousandths or hundredths of a second, between delivery of a signal and the subject's reaction. The experimenter depresses a key to simultaneously deliver the light signal and start the stopwatch, while the subject depresses his key upon seeing the light and turns off both the signal and stopwatch. The time recorded on the reflexometer corresponds to the period of development of successive physiological processes (perception of stimuli by retinal nerve cells, dissemination of excitation from retinal cells to cortical cells, passage of excitation from cells in the visual cortex to cells in the motor cortex, passage of excitation from cortical motor cells to spinal cord motor cells, passage of excitation from spinal cord motor cells to muscles, performance of specified movement) in different parts of the reflex system of man.

The time in which all these processes occur reflects reaction speed. A change in latency period of the reaction is largely determined by the speed of transition of excition from one neuron to another at the sites of contact between nerve endings of one cell and those of another, i.e., in the synapses.

Table 8 lists the rates of visual-motor reactions in the second hour of work involving numerous repetitions of simple movements and relatively insignificant expenditure of energy.

Table 8. Changes in rate of sensorimotor (visual-motor) reaction in the second hour of work in individuals engaged in manual labor not requiring much muscular exertion

Type of work	Reaction speed before work, s	Reaction speed in second h of work, s	Difference	
			s	%
Wrapping bricks of ice cream (conveyer)	0,35	0,27	0,08	23
Sharpening drills (work involving use of microscope)	0,32	0,25	0,07	22
Buffing drills on lathe [bench]	0,22	0,22	0,00	0
Adjustment of drills (free rhythm)	0,19	0,17	0,02	10
Mean values of parameters	0,27	0,23	0,04	14

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In view of the results of studies conducted with the use of the above-described procedures and equipment, it is possible to organize the mode of work on conveyers to make full use of the advantage of altering man's physiological functions, i.e., summation of traces of nervous excitation and time reflex.

There must be a pause between the end of one work operation and start of the next for optimum summation of excitatory traces and, consequently, adoption of the required work rhythm. This pause should be long enough so that the start of the next operation would coincide with the exaltation phase of the receding trace of excitation. If the pause is too short, there is rapid development of pessimum inhibition, decrease in speed and accuracy of work movements. This process is accompanied by development of sensations of monotony and fatigue in workers.

Numerous repetitions of the same actions, especially when they follow one another often, elicit the unique physiological effect of "hammering into a single cell" (I. P. Pavlov), i.e., excessive summation of excitation in a limited part of the cerebral cortex. In this case, the natural protective reaction of cortical neurons consists of developing inhibition, that prompts the individual to stop work that could lead to exhaustion of overloaded nerve cells.

Very long summation of excitatory traces after reaching the optimum excitation leads to reduction of motor lability and labor productivity. Short breaks are scheduled (with performance of exercises) for conveyer workers to prevent this undesirable phenomenon, and during these breaks there is restoration of efficiency and, to some extent, elimination of the effects of monotonous work.

Work on assembly lines and conveyers narrows significantly the field of activity of workers and reduces the content of work operations. By means of scientific organization of labor, this limitation and monotony of work can be overcome. For example, the experience of modern, progressive enterprises confirms the efficacy of having conveyer workers learn several operations and periodically switch from one operation to another.

It should also be borne in mind that, as a result of change in functional state of the body during the first hour of work, there is gradual assimilation of a fast work pace, which is maintained for several hours in the middle of the work day. By the end of the work day, there is a decrease in motor lability and some slowing of work actions due to excessive summation of traces of nervous excitation. For this reason, it is necessary to vary the speed of the conveyer belt. Special mechanisms are used to accelerate the conveyer belt at the start of the work day, hold its speed at a relatively high level in the middle of the shift and slow it down at the end of the work day. Such regulation of the speed of the conveyer belt in accordance with changes in functional state of the

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human body prevents excessive fatigue and makes it possible to keep a worker's efficiency on a high level.

Key Cycle of Self-Regulation of Physiological Functions During Mechanized Labor

Mechanized labor is characterized by higher productivity and increased precision of manufacturing products, since the performance of mechanical labor is relegated essentially to machines; precision technological operations are performed by means of appropriately adjusted mechanisms. The work of man in a man-machine system most often does not require considerable physical exertion, but it is related to increased attention, accurate visual and kinesthetic monitoring of the production process, performance of precisely coordinated, rapid work movements combining different motor functions of both hands. Depending on the conditions of interaction between man and machine, the main (technological) time, during which the technological process is performed in the man-machine system, may be a machine, machine-manual or manual process. The proportion between these types of work time can vary with different forms of mechanized labor. For example, in the case of high-speed cutting or mass production of simple parts on metal-cutting lathes, machine time constitutes about 60-80% of total work time and performance of manual operations constitutes only 20-40%. As a rule, the lathe operator is in "standing" position throughout the work shift.

Success of work on a metal-cutting lathe is achieved by means of formation of a complex dynamic work stereotype in the lathe operator. The presence of many elements (transitions) constituting the work operation of a lathe operator is indicative of the complexity of this reflex system: picking up a piece of stock, putting it in the chuck, securing the piece in the chuck, moving up the cutter, turning the lathe on, stopping the lathe, filing [sharpening], measuring, etc. Inaccurate performance of elements of the operations and related loss of time could reduce significantly the productivity of labor.

The design of modern lathes (for example, in machine-building) is such that manual work actions can be performed using different combinations of elementary movements. Finding variants that save the most time and permit using both hands is a factor that increases efficiency and labor productivity.

The time when traces of excitation from second-signaling system stimuli are associated with traces of direct (first-signaling) stimuli perceived by different analyzers while performing work operations on a lathe is a particularly important factor in formation of the integral image of work actions in a lathe operator. The functional state that develops with performance of each element of a complex operation on a lathe acquires a certain significance, not only for this special task, but to prepare optimal initial conditions for the performance of the next elements.

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In addition to formation and function of the integral image of work actions, conscious planning of work elements and operations is very important. A distinction is made between the following stages of planning: tentative, organized and planned execution.

In the presence of an integral image of work actions and conscious planning thereof, the lathe operator chooses the appropriate work movements. Performance of these work movements in machine-manual and manual elements of operations by a lathe operator is governed by their own psychophysiological laws. The most important of them is the law of concentration of muscular force on a short segment of space and time. By virtue of concentration of muscular force at the most favorable time, one can achieve optimum adaptation to lathe work during the actual movements.

For example, at one enterprise, outstanding lathe operators spent one-half less time on operations than other lathe operators. Complex cinecyclographic and electromyographic studies were conducted to determine the causes that prevented assimilation of progressive work procedures on a metal-cutting lathe.

Analysis of cinecyclograms and electromyograms of lathe operators differing in proficiency revealed that the best lathe operators showed concentration of waves of velocity and acceleration of movements when performing manual and machine-manual operations, as well as volleys of increased bioelectrical activity of muscles in short segments of time and short segments of the work trajectory of movements of different parts of the body, which enabled them to perform the operation the most efficiently.[67]

The key cycle of self-regulation in a man-machine system is characterized by man's constant influence, as the element of control of the machine, processing of information from the machine to man and performance of complex, accurate movements in accordance with a developed plan and integral image of work actions. To improve interaction between man and machine, one must determine not only how it is possible to reduce time spent on different elements of the operation, but the distinctions of key physiological functions: planning of the work operation (organizational and effector), formation and maintenance of an integral image of work actions, increased lability of afferent and efferent motor elements, concentration of muscular force and nervous processes (excitation and inhibition), development of a highly stable reflex system of the dynamic motor stereotype, muscular endurance under static and dynamic conditions.

Occasionally, in the practice of scientific organization of labor, the methods used for increasing labor productivity are reduced to demonstration of the best variant, accidentally discovered by a lathe operator, of performing a specific work operation and development of instructions to facilitate learning of this variant by other workers. Not infrequently, the instructions combine recommendations for performance of a set of movements, variants of which were found and refined by different workers. This method of rationalization of work movements of a lathe operator,

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which was named the method of engineer Kovalev, directs itself to the chance discoveries of the most productive variants of work movements and voluntary mechanical combination thereof into a complex lathe operation.

Engineer F. L. Kovalev describes this method as follows: "Three of the best women weavers, P. Kozlova, K. Anisimova and N. Chekina, who worked on several machines, overfulfilled their work quota considerably. But what was the most typical feature in the work of each of these Stakhanovites [outstanding workers]? We compared two of the main work procedures: changing the shuttle and repairing breaks in the sinker thread. It was found that Kozlova spends 2.5 s on the first of these operations, versus the standard of 2.8 s, Anisimova spends 3.2 s and Chekina spends 4 s. Consequently, only comrade Kozlova spends less time than required by the standard. It was a different matter for the second procedure, that of repairing breaks in the sinker thread. Here, comrade Anisimova spent the least time. She performed this procedure in 14 s, versus the standard of 16.5 s. The actual time spent on the same procedure was 25 s for comrade Kozlova and 30 s for comrade Chekina.... An in-depth study of the work process performed by the group of Stakhanovites according to different elements of the operation ... made it possible to demonstrate the distinctive features in the work methods of each worker, and to determine the most progressive general method of performing the operation by a weaver."[68]

A. S. Tolstykh writes: "... in order to really organize exchange of knowhow, one must find, study and generalize the constantly appearing progressive work procedures covering all occupations. It is known that different workers do not perform all procedures in the same way. One operation is performed faster and better by one worker, another by another worker. If we were to pick out the best procedures and combine them, learning these procedures would make it possible to perform the work in the best way."[69] A. S. Tolstykh explains his idea referring to the example of analysis of lathe work.

Planning the organization of labor by means of summation of time of performance of elements by the best workers has also become widely practiced abroad. The system of summation of microelements of work operations is used for preliminary estimation of time spent on proposed work operations. Some authors believe that this should replace the study of how work time is spent by means of time studies, the results of which may be inaccurate because of the subjectivity of the observer, and for this reason they are not suitable for planning a new work process.[70]

Such a method has also been developed for planning operations involved in mental work (working on control consoles), where there is summation of elements such as "operator's reaction time to signals," "time of arithmetic calculation," etc. (the "work factor" system). In 1966, a modular system of standards for work movements (MODAPTS) was developed. In the MODAPTS system, the module or mode is the unit for measuring expenditure of time,

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i.e., mean time of movement of a finger in a work operation that is well-learned. The mode equals 0.129 s. With addition of 10.75% for rest, the mode is 1/7th of a second.

All these systems have a common flaw: they do not take into consideration the physiological laws of combining movements and elements into an entire operation. When planning operations, it is imperative to pursue a comprehensive psychophysiological study of different elements, analyze the structure of these elements and movements from the standpoint of most efficient attainment of the work goal.

For example, in a study of the work method of an outstanding shoemaker, N. S. Smetanin, distinctive features were demonstrated with regard to rationalization of this innovator's work place, his procedures, separation of the work operation into elements, form and duration of work movements. Workers who wanted to learn the Smetanin work method organized their work places like his. Reverse movements were eliminated, which reduced, to some extent, the time of production per unit. However, their output continued to lag significantly from that of N. S. Smetanin. In order to help learn the Smetanin method of working, it was necessary to determine, by means of physiological analysis, the differences in content of elements of operations performed by N. S. Smetanin and the other workers.

Cyclographic analysis revealed that the distinctions of the work of N. S. Smetanin consisted of combining the movements of picking up the stock and putting away the ready product, with kinesthetic analysis of the object of labor.[71] The elements of "taking the stock" and "putting away the processed article" were performed considerably slower than the speed of the same movements in other workers.

Many workers, like the standard setters, believed that one should reduce the time required on each element of a complex operation in all cases, without exception, in order to reduce the time spent on this operation. Psychophysiologists explained the fallacy of the conception of a complex work operation as the mere sum of its elements: while N. S. Smetanin was slower in the ancillary elements of picking up and putting away the object of labor, he performed the main elements of the work operation faster than other workers thanks to combining ancillary movements of kinesthetic examination of the distinctions of each piece of stock and checking the result of the operation.

Knowledge of the key physiological functions in a machine operator makes it possible to effectively solve problems of refining work processes in lathe operations. Individuals who instruct workers must, in addition to teaching them the most progressive work methods and procedures, aid in the formation of proper conceptions of the goal of the work operation and stages of attainment thereof, the integral image of the necessary work actions. Written instructions, detailed instruction charts and self-checking by the worker are very helpful in achieving this. Lability of

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the motor system, concentration of nervous processes and muscular force can be increased by means of special exercises on a simulator (see p 73). Learning the different movements of a skilled worker by means of imitation is relatively less significant in assimilating progressive work methods. Planning work operations without consideration of development of the above-mentioned key physiological functions by means of mechanical combination of the best work procedures adopted from various workers is even less effective.

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CHAPTER 6. PSYCHOPHYSIOLOGICAL BASES OF MENTAL WORK

Key Cycle of Self-Regulation in Work Requiring Close Attention and Solution of Mental Problems

At the present time, the area of application of mental labor is increasing significantly, and the number of workers engaged in mental activity is growing. At the same time, the nature of physical labor is changing; it is saturated with elements of mental labor, and some forms of physical labor are becoming increasingly creative.

For example, A. A. Vasil'yev writes: "The labor of a modern, highly skilled worker who supervises the work of an entire brigade on the assembly of an extremely complex machine, who has at his disposal a set of blueprints and charts, high precision measuring and monitoring instruments, is largely mental labor...."[72]

Polytechnical, general and industrial education is becoming an important means of eliminating the still remaining differences between mental and physical labor. Elimination of differences between mental and physical labor results in approximation of qualification requirements made of a worker and engineering and technical personnel. Accordingly, there is a gradual reduction of the gap between the level of mandatory general education, on which is based the training of engineers at VUZ's, and the training of skilled workers in vocational schools. At the present time, we can encounter individuals among blue-collar workers who are familiar with the fundamentals of many physical and engineering branches of knowledge.

Expansion of production functions of workers and saturation of their labor with creative elements constitute the main trend in development of industry. However, in addition to this tendency, there is also excessive narrowing of specialization, due to the inadequate level of mechanization and automation of industry. From the psychophysiological point of view, excessive specialization becomes the cause of loosing interest in work, developing a sensation of monotony and rapid fatigability.

What is the physiological distinction of mental labor, as compared to physical? We could only be dealing with a relative, but not absolute difference. Not infrequently work that does not require physical exertion

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or lifting heavy articles, or overcoming resistance of the object of labor, etc., is referred to as mental labor. Such a definition cannot be satisfactory, since it is necessary to know the positive, distinctive features of mental labor for rational organization thereof.

The distinction that the objects and results of mental labor are not tangible things, but designs, images thereof, instructions and information is an important feature of mental work.

Elements of mental labor are represented in different proportions in many types of work, including those requiring physical exertion. Modern types of work can be classified as follows, according to the index of increase in share of actually mental activity:

Transitional form of labor: in this group of jobs, there is a combination of elements of mental and physical work, for example, the work of lathe operators, adjusters on automated lines, operators of simple control consoles.

Mental labor in which there are elements of muscular work, but the latter does not play a decisive role. In this form of work, use is made of previously developed skills, close attention and analyzer functions are required, for example, the work of inspectors [checkers] on automated lines, operators of some of the subway signal boxes.

Mental labor related chiefly to intensive, extensive attention, solution of new problems and changes in work plan, for example, the work of processors in a system of mechanized accounting, stereoscope specialists, editors, stenographers.

Mental labor requiring much knowledge, intensive and creative activity, for example, the work of directors at the control console in a television studio, railroad dispatchers (at major railroad stations).

Mental labor directed toward attainment of long-term goals, for example, work in the fields of instruction (pedagogue, foreman, brigade leader), design (scientist , engineer, designer, architect) and planning (director, supervisor).

Within each of these five groups, we can distinguish subgroups according to degree of tension of physiological functions, composition of functions carrying the main load and the specific tasks performed by the workers.

Analysis of the foregoing, which does not presume to have exhaustively covered all forms of work, shows that each of the five work groups contains elements, such as planning of actions, remembering technical conditions of the operations performed; all of the forms of activity, without exception, require intense attention.

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These psychophysiological processes also occur in heavy physical labor, for example, the work of metallurgists, miners, smith forging blacksmiths, etc.; however, they are not represented there in pure form, but against the background of intensive muscular work; but their presence is indicative of the possibility of a creative approach to the work, which is manifested, for example, by inventiveness and development of rationalization proposals.

When a basically new solution is found for a problem, we refer to creativity. As a rule, industrial, scientific and particularly artistic creativity is considered as a mysterious process to some extent. Creativity is, first of all, impressive in its unique results, development of material and spiritual values, which most often have no equal in the past. Not everyone who learns of the results of creative activity comprehends the enormous, time-consuming and intensive work of the author of a product. For this reason, such expressions as "mystery of talent," etc., are widely used. Studies of this "mystery" make it possible to aid in development of creativity in all areas of human endeavor and to create beneficial conditions for creative work.

The efforts that have been made by psychologists to use tests to examine the distinctions of individuals engaged in creative work (chess players, inventors, scientists) did not demonstrate any "definitely marked traits in the creative personality."[73] The creative workers themselves are often hard pressed to explain the source of their own creativity, although their statements are very important to disclosure of different aspects of this process, and to the search for approaches to teaching creativity.

A. S. Pushkin, in his poems entitled "Autumn," "Conversation Between a Bookseller and Poet" and others, demonstrated the significance of inspiration, of a special emotional enthusiasm in creativity. However, we know how much labor went into his works, how laboriously and intensively he worked on them, meticulously choosing an accurate definition, or word as he developed a composition.

P. I. Tchaikovsky also stated that even the great musical geniuses occasionally worked without the warmth of inspiration. He attributed much importance to an individual's ability to work neatly, systematically and diligently. P. I. Tchaikovsky wrote: "... one has to work all the time, and a genuine, honest artist cannot sit with his hands folded with the excuse that he is not in the mood. If one waits for the mood and fails to try to search [meet it half way] for it, it is easy to become lazy and apathetic. One must be patient and have faith that inspiration will inevitably come to him who was able to conquer his indisposition.... Inspiration is a guest who does not like to visit lazy people. It comes to those who invite it."[74]

We could cite many more examples and quotations that confirm the need for constant and intensive work in any creative process.

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Thus, the presence of innate inclinations, which are appropriately developed, and meticulous, systematic work constitute a prerequisite for successful creativity. For this reason, the methods of educating creative workers and teaching creativity should be directed toward development of abilities and diligence, of maintaining emotional enthusiasm. Modern pedagogics and psychology do not have adequate methods for performing this task. In Soviet pedagogics, the ability to operate "mentally," to develop "an internal plan of action," is considered to be one of the most important distinctions of the creative personality, and it is assumed that solving theoretical problems is the principal means of developing this ability. However, refinement of this ability had not been singled out on a broad scale as a special objective of education.[75]

The flaws in psychological theory of creativity are related to the limitations of the narrowly psychological approach to this problem, which underestimates the innate basis of creativity and thinking. Thinking and cognition are a social product, both with regard to distinctions of their appearance and method of function, as well as results; however, they are inseparably linked with sensory and physical processes in the nervous system. In scientific organization of labor, this thesis acquires decisive significance, since it is only with consideration of social and natural elements that it is possible to aid in development of a worker's creative abilities.

The physiological basis of creativity is that, in response to social stimuli, a socially significant activity occurs, which is associated with specific processes within the body--emotions, manifested by a change in vegetative processes, intensive higher nervous activity and others.

From the physiological point of view, to assure fruitful creative work, it is necessary to form a particularly stable, well-organized system of reflexes, the dynamic work stereotype, involving different nerve centers and, first of all, the cortical ones. Under ordinary conditions, each of these centers can perform some limited vital function at the rate that is inherent in this function. But when this nerve center becomes an element of the reflex system intended for participation in creative work, it must govern the pace of its activity to the general pace of the system. A. A. Ukhtomskiy explains this "tuning" of the functional system, or constellation of nerve centers, on the example of the verbal reflex system. "It is easy to realize on the basis of self-observation how relatively fast a thought occurs and is formed, which awaits expression, and how relatively slowly the initial statement is made, and it involves conflicts. The lack of conformity of pace and speed often leads to the situation where efforts to express a thought verbally, which proceed in spurts and with difficulty, begin to disrupt the train of thought and, as a result, there is inhibition of the speech process ... it is only with mutual attuning to a certain average 'sympathetic rhythm' of work (i.e., partly by reducing the faster paces of activity of some elements and partly by accelerating the slower paces of other elements) that the speaker achieves a uniform

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march of excitations in the verbal constellation of centers."[76] And, further: "Speech becomes a dominant process when the appropriate central constellation is more or less completely involved in the process, the adjusted rhythm of stimuli is uninterrupted and reinforced by current impressions of the environment, whereas the nearest and myopic reflexes to these current impressions are transformed and removed from the line on the order of conjugate inhibition."[77]

V. M. Bekhterev, who analyzed the process of creativity from the standpoint of reflexology, arrived at the conclusion that such activity is based on appearance of a dominanta in mental activity. For creative thinking and inspiration, "the stimulus is the problem, while the response to it in the form of reaction or series of reflexes is the activity that leads to creative achievements."

"What is the mechanism of action of the stimulus-problem? It stimulates, first of all, like any strong stimulus, concentration on the problem, so to speak, concentration of the effector mechanism on this problem, which is a sort of dominanta in mental activity, i.e., a process of excitation that attracts, like a center, stimuli from other parts of the brain and, at the same time, inhibits all other stimuli that are inconsistent with it."[78]

These statements by A. A. Ukhtomskiy and V. M. Bekhterev make many internal processes occuring during creative activity understandable. First of all, we refer to the exceptional responsiveness of man, of his nervous system, to new stimuli, concentration related to distraction from numerous repetitive signals that do not carry new information, and the presence of a large store of information. Amazing conjectures and intuition may be inherent expressly in subjects who are controlled by such a mighty dominanta. By virtue of accumulated knowledge, a man rapidly solves a complex problem without analytical separation of the problem into minute elements, as if "guessing" at the means of solving it.

At the present time, science does not have complete enough data on physiological processes that take place during mental labor. The pertinent facts could be obtained from studies in the laboratory and industry. In such studies, more accurate analysis should be made of processes indicative of the presence of foci of heightened nervous activity (heightened excitability and functional lability), as well as of conjugate inhibition of reflexes that are not consistent with ongoing activity, in subjects engaged in mental and creative work.

At the present time, physiologists have obtained data confirming the conclusions of A. A. Ukhtomskiy and V. M. Bekhterev concerning physiological processes associated with the function of the different dominantas of mental labor. In particular, experimental studies were made of the physiological processes at the basis of guesswork, which often helps people in creative professions (engineers, physicians, pilots, pedagogues, etc.) solve complex, nonstandard problems.[79] For this purpose, a record

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was made of galvanic skin reflexes (changes in electric potentials of the skin), which are an indicator of higher nervous activity. A mild galvanic skin response was observed in individuals who rapidly guessed at the means of solving nonstandard problems; in those, however, who had difficulty in solving them, the duration and intensity of the galvinc skin response increased. This means that in representatives of the first group of subjects there was significant increase in lability and excitability of neurons, as a result of which foci of heightened activity or, according to A. A. Ukhtomskiy, "a constellation" of nerve centers with coordinated function. This "constellation" is notable for its capacity to summate excitation and lability, as well as of inhibiting reflexes (in particular, galvanic skin responses) that do not conform with the main activity at a given time. Stimuli that induced a given reflex are perceived in the presence of the dominanta, but instead of the usual reaction they elicit intensification of the predominant reflex.

These conclusions are also confirmed by the effects of stimuli of the second signaling system on the process of performing simple work. While recording muscular function on an ergograph, the subjects were asked to perform mental arithmetic. At the start of the exercise, when the dynamic stereotype and dominanta of modeled work were not yet fixed, mental arithmetic made movements difficult. At the next stages of practice, this factor no longer affected muscular work. Arithmetic, as a stimulus of the second signaling system, was stronger than a stimulus such as muscular work (first signaling system). At the start of exercise, mental arithmetic elicits inhibition of motor activity in accordance with the law of simultaneous induction. But at the end, two equally strong dominantas developed, and there was more distinct separation of areas of summation of traces of nervous excitation in the cerebral cortex. Thus, beneficial conditions were created for simultaneous physical and mental labor.[80]

With voluntary attention that is required for precise movements and perception of information, a physiological mechanism of formation of a cortical dominanta is also in effect. Voluntary attention is characterized by man's being so submerged in his work that he does not perceive various accidental, extraneous stimuli. But if extraneous stimuli are actively inhibited, there must also be a rather strong source of inhibition, a focus of increased activity in the cerebral cortex. The presence of such a focus is manifested by a reduction of latency period of reflexes essential to a given job and concentration of muscular force and nervous processes on the main direction of activity.

Such phenomena are observed, for example, when determining the speed of a motor reaction in response to seeing a moving object (pointer) reach a specific point. When the subject reacts to two pointers, each moving over its own dial, the speed of reactions to movement of both arrows is about the same. But if the subject is asked to count the number of revolutions made by one of the pointer and, consequently, to pay special attention to this pointer, the reaction speed changes: the latency period

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of the motor reaction to the pointer, whose revolutions are being counted, by the subject, becomes shorter than the latency period to movement of the other pointer.[81]

Studies of electrical phenomena in the cerebral cortex elicited by photic stimulation (studies of school children) also revealed that heightened attention influenced the reaction. So-called evoked potentials, in the form of biphasic waves with a negative maximum, were demonstrated in cortical cells during perception of flashes without additional stimuli (sound) and without fixing attention on the number or intensity of flashes. With consideration of number of flashes and evaluation of their intensity, as well as with the use of an additional stimulus, the subject showed a reduction of the latency period, increase in maximum of electric reaction (evoked potential) and shorter time of its development. These phenomena were the most distinct in older school children.[82] The increase in maximum of bioelectric reaction with concurrent reduction of its interval is indicative of concentration of nervous excitation, which is inherent in appearance of the dominanta.

We compared under industrial conditions the intensity and lability (mobility) of physiological processes in workers who mainly had to solve stereotype problems and workers who solved predominantly new work problems.[83] We chose plant designers and copiers (Frezer Plant) as the models. In representatives of these groups of individuals engaged in mental labor, we determined the intensity of the main nervous processes (excitation and inhibition) during work, with formation and maintenance of the reflex systems specific to each form of work (special work dominantas).

Designers are periodically given assignments to design new products (mainly lathe attachments). In creating designs of variants of problem solving, the designers use their experience, taking into consideration new achievements in a given field, and they are governed by instructions in numerous manuals and GOST's. Designs are discussed in the chief designer's department and in the shop, after which blueprints are made. In the course of manufacturing an article from these blueprints, the designer checks the workers involved. Success of such work is assured by the constant concentration of the worker on his nonstandard problem and, consequently, presence of the appropriate cortical dominanta.

The above-described work elements are lacking in copiers. Their work is strictly regimented and limited to copying an existing blueprint.

Intensity and speed of the main nervous processes in both groups of specialists were determined from the rate of extinction, leveling off of traces remaining in the subjects after differentiation inhibiton. Extinction of traces was much faster in designers than copiers. It constituted an average of 20 s in the former, whereas it was incomplete in the latter even after 30 s.

Thus, from the pyschophysiological viewpoint, formation of an appropriate dominanta is a prerequisite for fruitful creative work. The task for industrial psychophysiology is to maintain dominanta function on a high level and increase its stability. Science must determine the causes of impairment of the dominant, decrease in efficiency of individuals engaged in mental labor and, particular, creative workers, and develop recommendations to alleviate mental labor, optimize the conditions thereof and increase its efficiency.

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Various authors have studied autonomic functions in order to examine the dynamics of efficiency of individuals engaged in mental labor, although, considering the importance of the key physiological functions, they should have studied the formation and impairment of the reflex system governed by the prevailing excitatory focus in the cerebral cortex.

Studies of respiratory and circulatory functions in individuals engaged in mental labor revealed a decrease in amplitude of respiratory excursions, shortening of phases of respiration and an increase in heart rate.

According to the data of V. G. Kryzhanovskiy, who studied the mental work done by students [college level], the changes observed in the subjects' heart rate occurred at the times they switched from rest to mental work.[84]

No conclusive results were obtained from efforts to rationalize mental labor on the basis of data pertaining to changes in parameters of cardiovascular function in the course of a work day.[85] At first glance, this finding is not consistent with observations that confirmed a link between mental fatigue and diseases of the cardiovascular system.[86] The seeming contradiction between the results of studies of the dynamics of cardiovascular functions in the course of the work day and over longer periods of time (weeks and months of work involving considerable mental tension and unrational organization of labor) is resolved by the fact that pathological circulatory disorders occur as a result of prior change in dynamics of higher nervous activity. In particular, according to modern neurogenic theory, hypertension is preceded by neurosis of higher nervous branches of the neurohumoral system that regulates arterial pressure. Modern medicine maintains that "essential hypértension is based on disturbances of central nervous regulation of a stable arterial pressure. It occurrs ... under the influence of various emotional, as well as traumatic, effects on the cerebral cortex and subcortical centers. This leads to stimulation of the vasomotor center, extensive spasm of small arteries and arterioles, and elevation of arterial pressure."[87]

Special studies directed at demonstration of a link between impaired dynamics of higher nervous activity and condition of the cardiovascular system of individuals engaged in mental labor established that there is a correlation between a number of signs of impairment of dynamics of higher nervous activity and functional changes in the cardiovascular system. Thus, according to the data of A. M. Prosekin, in telegraph workers there is an increase in complex motor reaction time and decrease in labor productivity concurrently with increase in mean dynamic blood pressure, which occurs concurrently with development of fatigue during the work shift. This author believes that, in this cases, we are dealing with "neurosis, which leads to impairment of compensatory capabilities and onset of hypertension."[88]

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Thus, there must be optimum nervous processes in the higher branches of the central nervous system to keep efficiency of mental labor on a high level.

While successful performance of mental labor is based on formation and function of special reflex systems--dynamic work stereotypes--governed by a focus of heightened activity (constellation of nerve centers notable for a high level of excitability and functional lability), a decline in efficiency of mental labor apparently starts with disturbances in this reflex system. Consequently, in order to maintain a high level of efficiency and prevent fatigue among such individuals, it is imperative to monitor the stability of their reflex systems and use preventive measures at times preceding the expected disturbance in the system and corresponding decline of efficiency. This can be done if the physiological mechanism of impairment of this reflex system is disclosed, if the external manifestations of this disturbance are known and if methods are developed to measure it.

We have shown that extremely strong opposite processes, excitation and inhibition, are present simultaneously and interact in the individual's cerebral cortex in all instances of mental activity. While excitation maintains the main activity, inhibition precludes any possible incidental reactions that do not conform with this activity, such as the galvanic skin reflex, movements during performance of simulated work on an ergograph, etc. Interaction or, as I. P. Pavlov put it, a clash, "collision" of excitatory and inhibitory processes, leads to depletion and destruction of nerve cells, and in extreme cases excitation or inhibition could diminish drastically, and this disrupts the equilibrium between them. Very advanced impairment of equilibrium of the main nervous processes leads to development of diseases of the neurosis type. I. P. Pavlov cites examples of such a clash between excitatory and inhibitory processes: inability to respond to an insult, inability to inform a close friend about his hopeless situation, etc.[89] There can be various external expressions of profound impairment of equilibrium between the main nervous processes, depending on the type of nervous system. If the victim of a neurosis is referable to the markedly excitable type, he performs unnecessary actions and cannot stop in time, but if he is referable to the markedly inhibitable type, it is difficult for him to perform the required actions, etc.

With lengthy mental labor, in the instance where its organization is unsatisfactory, there may be gradual development of a clash between the main nervous processes and neurosis may develop. During prolonged work, there is continuous summation of traces of nervous excitation, which leads to increased intensity of nervous processes, thereby accelerating onset of impairment of equilibrium thereof. For this reason, one must determine the critical moment, when it is imperative to avert impairment of equilibrium of the main nervous processes by means of organizational measures. It is particularly important to eliminate such flaws in organization of labor as idle periods, rush work, etc. If there are such flaws, the workers perform their task by drawing on increased conative efforts and using the strong stimuli of the second signaling system. This may be associated with

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emotional reactions that affect the functional state of nerve centers. Excitation that then appears in the nervous system spreads widely over the body and involves many muscle groups and internal organs, in particular the cardiovascular system. As a result, there can be excessive and prolonged elevation of blood pressure, which causes onset of essential hypertension, with localized dilatation or constriction of vessels in organs of the digestive system that is instrumental in development of peptic ulcers, etc.

Protective inhibition is the natural reaction of nerve centers of the cerebral cortex to excessively strong or repeated stimuli. Most often protective inhibition is encountered and manifested more markedly during intensive mental work; for this reason one must examine its origin and significance to dynamics of higher nervous activity.

In his studies, I. P. Pavlov showed that a special variant of inhibition appears with overexcitation of higher nervous activity; the role of this inhibition is to protect and defend the most reactive and most delicate nerve cells of the cerebral cortex, rather than to coordinate, along with excitation, processes of vital functions. I. P. Pavlov wrote: "On the one hand, there is constant inhibition, on a par with stimulation, which is involved in diverse animal activity in a waking state; on the other hand, it plays the role of protector of the most reactive cells of the organism, the cerebrocortical cells, protecting them specially against excessively intensive activity upon encountering very strong stimuli, during repeated delivery of stimuli that are not so strong, and providing them with the necessary rest after normal daily work, in the form of sleep."[90] The cortical neurons do not have a large reserve of nutrients and, at the same time, they consume tens of times more oxygen than cells of other tissues and organs.

It is of first and foremost importance to take into consideration the intermediate phases of development of protective inhibition when preparing recommendations to keep mental efficiency on a high level. I. P. Razenkov observed these intermediate phases in animal experiments.[91] In one of the experiments, after rapidly and directly changing from an inhibitory stimulus to an excitatory one, he observed virtually complete absence in experimental dogs of all conditioned reflexes, i.e., the effect of a clash between excitation and inhibition. This condition lasted 10 days. Then, within 5 weeks there was restoration of efficiency of the cerebral cortex, and changes were observed in reactions to stimuli. For 2 weeks, strong stimuli did not elicit a reflex, whereas weak ones elicited the maximum effect. In the next week, the nature of the reactions changed: all conditioned stimuli, both strong and weak, elicited conditioned reflexes of the same magnitude. Ultimately, there was restoration of the dog's higher nervous activity, and the usual correlation was observed between level of conditioned reflexes and force of stimuli, in accordance with the so-called law of force: a weak response to weak stimuli and a strong one to strong stimuli. Thus, there was demonstration of three stages of changes in results of stimulation:

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first stage, inhibitory (absence of all positive reflexes); second stage, paradoxical, in which weak conditioned stimuli elicited a greater reaction than strong ones; third stage, equalizing one, characterized by the fact that idenitcal conditioned reflexes occurred in response to stimuli differing in force. While I. P. Razenkov studied the stages of recovery of impaired activity of the cerebral cortex, I. S. Rozental' observed the sequence of phases of hypnotic inhibition in the course of prolonged use of positive conditioned reflexes.[92] The phases followed one another in the following order: normal, equalizing, paradoxical and inhibitory.

Discovery of protective inhibition in the case of numerous repetitions of positive conditioned reflexes was of great interest to industrial psychophysiology, since it warranted the belief that if analogous patterns and processes were demonstrated in higher nervous activity of a working man it would be possible to predict the moment of decline of efficiency of individuals engaged in mental labor on the basis of manifestations of early phases of hypnotic inhibition, and to prevent it by means of the appropriate measures.

T. N. Pavlova checked this hypothesis in an industrial experiment, which she conducted at the First Moscow Factory of Mechanized Accounting.[93] She proved the presence of protective inhibition in dynamics of higher nervous activity, as well as the phases thereof. It then became possible to determine the specific analytical methods for studying changes in efficiency of individuals engaged in mental labor and, on the basis of the results obtained with these methods, to elaborate pertinent recommendations for rationalization of mental labor and improvement of conditions thereof.

The dominanta that are formed during mental labor differ in that there is such great nervous tension and complex interaction between excitatory and inhibitory processes that there is a danger of functional exhaustion of cells of the cerebral cortex, and protective inhibition, also called supraliminal, is the reaction to it. This reaction occurs when the nerve centers of the cerebral cortex begin to be threatened with functional depletion as a result of their very intensive function (depletion of reserves of adenosine triphosphate, electrical charges, enzymes, etc.). Protective inhibition compels the individual to stop the work activity, which became a factor that is deleterious to health and efficiency. However, according to the results of physiological studies, man often continues to work, even in the presence of protective inhibition, overcoming its signals with intensified, voluntary nervous impulsation.

The first sign of such a clash between protective inhibition and voluntary increased impulsation is the spread (irradiation) of heightened excitation to different muscle groups and internal organs. Upon further continuation of exhaustive work, protective inhibition develops in the equalizing and paradoxical hypnotic phases. These phases are seldom seen in workers engaged in physical labor, since biochemical processes in muscle tissue lead to such a decline of muscular force that it is impossible to maintain the required muscular exertion and continue to work, before protective inhibition has time to reach a high enough level.

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Appearance of the equalizing and paradoxical phases of portective inhibition, which is indicative of very advanced decline of efficiency that is hazardous to health, was observed by physiologists in workers engaged in mechanized accounting,[94] as well as in school children in the case of an unrational work and rest schedule.[95]

For scientific organization of mental labor, it is important not only to demonstrate drastically diminished efficiency, but to prevent it, and for this purpose one must know the stage of this decline. At the present time, some objective signs have been found of gradually progressing fatigue with increase in intensity and duration of mental labor. One should consider as the first sign of fatigue during mental labor the impaired function of nervous inhibition and, first of all, differentiation inhibition, which appears in response to a specific stimulus. The next stage of development of mental fatigue is impairment of the excitatory process, which is manifested by a decrease in force and speed of reaction to a signal, in response to which one has to react strongly and rapidly according to the instructions. Further development of mental fatigue leads to appearance of equalizing and paradoxical phases of protective inhibition.

When setting standards for intensity of mental labor, it is imperative to take into consideration these stages of development of mental fatigue. Optimum adaptation of man to the conditions of mental labor involves activity, during which a high level of labor productivity is combined with moderate increase in reaction time, concentration of attention and processes of nervous excitation and inhibition, with increase in volume of memory and stability of associations.

Infraction of the law of force and presence of equalizing and paradoxical phases of protective inhibition are a sign of a state of the nervous system that precedes neurosis, on the basis of which there can be subsequent development of diseases of the cardiovascular system and viscera. The time of appearance of signs of equalizing and paradoxical phases in the dynamics of higher nervous activity is critical, i.e., at this time the intensity of work increases to the maximum permissible level, after attainment of which continuation of work leads to development of pathological processes.

The presence of signs of protective inhibition in individuals engaged in mental labor is indicative of unsatisfactory organization of their working conditions. Rational organization of the work of such individuals implies the use of preventive measures against possible fatigue and overfatigue at the early stages of declined efficiency related to fatigue, i.e., the earliest signs of impairment of inhibitory function of the nervous system.

Thus, studies of the dynamics of higher nervous activity resulted in elaboration of criteria for optimum adaptation of individuals engaged in mental labor to their work, criteria for the need of preventive measures against possible fatigue and criteria for the need of a radical change in the entire situation, in which a given form of mental labor is performed. With these criteria it becomes quite possible to indicate, in each specific case, the normal intensity of mental labor and means of optimizing its conditions.

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Some methodological difficulties are involved in determining the start of impairment of the inhibitory process. Estimation of the percentage of impairment of differentiation inhibition, in relation to the total number of differentiation stimuli delivered during different hours of the work shift, is the simplest means of determining this moment. However, this method is labor-consuming and inaccurate, since one has to check the effects of many differentiation stimuli to find this parameter; one has to repeat estimation of percentage of disturbances of differentiation inhibition many times at short (30-60 min) intervals in order to determine the time when weakening of inhibitory function begins to be manifested. The examined workers are detracted from their work in order to estimate the percentage of disturbances of differentiation inhibition, and this diminishes significantly the accuracy of the results obtained.

A more effective, convenient and accurate method is based on the use of a dynamoreflexometer (Figure 11). It is used to determine the magnitude of deviations (in arbitrary units, for example, microamperes on the microammeter dial installed on the instrument panel of this device) of the subject's exertion from the specified level (for example, 50 or 20% of this subject's maximum exertion).

In industry (for example, among operators performing monotonous work), in some cases one observes a special form of inhibition, a preventive decline of excitability under the influence of weak and sedative stimuli, the biological significance of which is to preclude insignificant stimuli. This inhibition elicits a decrease in efficiency and labor productivity of operators already during the first hours of work, when the possibility of functional depletion is unlikely.[96]

Experimental models of this phenomenon were obtained by physiologists in their studies of animals. A. A. Ukhtomskiy includes, for example, calming of an irritated animal after becoming satiated in this category of decreased excitability.

In the experiments of I. P. Pavlov, there was onset in dogs of inhibition under the influence of weak stimuli; unlike the inhibition elicited by strong stimuli, removal of the inhibitory effect in this case was possible with the use of new moderate stimuli, rather than rest.

Psychophysiological Conditions of Creative Activity

Industrial psychophysiology is not trying to offer an exhaustive explanation for the occurrence of creative activity, but it must disclose the physiological basis, which makes this complex form of man's conscious activity possible. Formation of a specific reflex system is such a basis, i.e., the dynamic work stereotype with distinct ability to become strengthened with delivery of stimuli from the environment and to depress reactions that do not conform with them. This reflex system has the properties of a dominanta. We call it the dominanta of creativity. We can assist creativity

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by psychophysiological means to the extent that we can influence this dominanta.

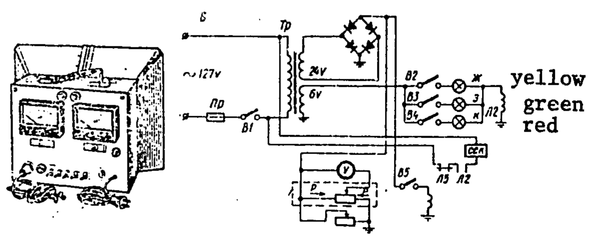

Figure 11. Simplified electric circuit of dynamoreflexometer

A) view of instrument; left dial shows force that subject applies to sensor and the right shows the latency period of motor reaction to lighting up of lamp situated on the rear panel

Б) circuitry of instrument; current travels from the power source through a transformer in three directions: a) to stopwatch, b) to sensor of subject's exertion (rectified current, 24 V) and c) to signal lamps (yellow, green and red, 6 V)

Key B1 is closed when instrument is in operation. So long as one of the keys (B2, B3, B4) is not closed, there is no current in the circuit. When the experimenter closes one of these keys, there is current in the low-voltage circuit, one of the lamps lights up, relay Л2 turns on high-voltage current (127 V) and the electric stopwatch begins to run. The subject, upon detecting the light signal, performs a motor reaction (depresses the sensor strongly when a red light goes on, weakly when a green one goes on and does not touch it if the yellow light is on). With minimal depression, contact B5 is closed and disconnecting relay Л5 is triggered. After turning off the low-voltage circuit and releasing the system, the entire system returns to the initial state

The most important prerequisite for creative activity is also formation of an integral image of the necessary work actions, as the physiological condition for elaboration of an internal plan of action, which is needed for proper creative activity.[97]

In creative retrieval, activity is separated into logically successive steps. A convenient form of such separation, in the form of algorithmic instructions, was developed in applied psychology. Such "instructions" are used in Soviet engineering psychology, and the questions is being raised of integral consideration of psychological processes that occur during the work of an operator, as well as the entire set of equipment that influences the effectiveness and complexity of these processes. In the United States,

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systematized instructions for the design and search for solutions to design problems are substantiated primarily by the results of observations and experience of instructors and firm management, less attention being given to the psychophysiological aspect of creativity.[98]

Man has a certain innate predisposition for creative behavior. That such predisposition exists is indicated by the presence in man (as well as higher animals) of the orienting reflex, or the "what is it?" reflex, and goal reflex. With reference to the orienting reflex, I. P. Pavlov observed that "this reflex has enormous biological meaning. If an animal did not have this reaction his life would hang on a thread in every minute. But in us, this reflex is very far-reaching, and it is finally manifested in the form of the curiosity that creates science, which offers and promises us the highest and unlimited orientation in the world around us."[99] With reference to the goal reflex, I. P. Pavlov said it was a primary instinct, and "all life is the attainment of a single goal, expressly that of protecting life itself, the untiring function of what is called the general instinct of life."[100]

Both of these innate reflexes develop continuously in the course of man's life: starting out as the most elementary reactions, they attain the level of supreme scientific orientation in life and in this complex state they are instrumental in creative behavior. The most general patterns of development of these reflexes and man's gradual ascent to creativity are already manifested at the early stages of man's individual development.

We studied the development of the need for man to independently, creatively and uniquely solve interesting problems in toddlers using the game situation.[101] A training toy is given to the children; it contained a small stand with an interesting object for the child (mosaic, candy) within a transparent housing. This object could be reached and taken by properly depressing a small lever with the right hand. The little stand turned upon application of specific force and with specific amplitude of lever movement, matched an opening in the top of the housing, and the child could then take the object with his left hand. The child's manipulations of the lever were recorded on mechanograms. As a result of these studies, it was established that children between the ages of 15 and 24 months learn how to properly depress the level following a specific pattern. The entire training period could be divided into four stages. The first consisted of learning the problem; it lasted until the children began to depress the trainer lever independently. The second stage was the period during which the child made exploratory trials of the best variant of movement, at which time the mechanograms showed pauses between movements, during which the child selected the best variant. The third stage was referable to completion of the search and further definition of movements (reduction in number of mistakes). The fourth stage was referable to proper performance of movements. At the second and third stages, the children separated movements (exploratory stages) and analyzed visual and kinesthetic information received as they observed the object coming closer to them and

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changes during their own efforts directed toward overcoming the resistance of the lever. At the end of the third stage, the children formed an image of the necessary actions (physiological basis of the internal plan of actions), according to which they corrected their movements at the next, fourth stage of the training period.

The possibility of creating problem situations is considerably broader in secondary schools, where students acquire skill in independent solutions for nonstandard class problems. Thus, at school No 70 in Moscow, elements that oriented students toward creative activity were included in the nature of an experiment in the curriculum of vocational training in radio electronics.[102] In another school, a specially prepared set of technological design problems and practical laboratory work was used to develop creative abilities of the students. The gradually more complicated assignments in this set activated perception of new material and improved solutions of technological design problems.[103]

Problem situations are encountered at every step in the practical endeavors of adults, particularly if we consider the increasingly complex problems that are being solved by the national economy, science and art.

The opinion is held, without full justification, that the creative process is lacking in the vast majority of occupations, the representatives of which perform strictly regimented work. This opinion is voiced by some psychologists without substantiation,[104] and it is often encountered in the general press.[105]

Our life, work and the creativity of many Soviet people have long since refuted such a conception. Socialist competition and its highest form, the movement for a communistic attitude toward labor, are indicative of a constantly developing creative attitude to work by millions of working people engaged in the most diverse sectors of industry.

For example, the practical application of methods of brigade cost accounting indicates that on-time delivery of a construction project with a good quality of execution requires that workers and brigade leader solve nonstandard problems, that are not standard and attributable to the specific situation at the building site, such as utmost use of work time and equipment, economical use of raw material and supplies, and use of methods of scientific organization of labor.

The experience in making use in the national economy of discoveries, inventions and rationalization proposals shows that the creative initiative of the multimillion mass of workers is making an active contribution to the development of science and technology in our country, accelerating scientific and technological progress, and is aiding in refinement of social production, as well as increased labor productivity.

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Psychophysiological Methods of Studying Efficiency* of Mental Work

The volume of performed work can serve, to some extent, as a characteristic of efficiency of mental work, since this volume decreases in the presence of fatigue and corresponding decline of efficiency.[106] However, this parameter is not accurate enough, since, under the influence of social motivation for work, a man can mobilize compensatory capabilities of his body and continue to work against the background of diminished functional state when he is tired. We have discussed the possible consequences of such mobilization. It is imperative to provide for an optimum functional state of a worker in order to rationally organize mental labor and hold its productivity on a high level.[107]

One can assess the functional state of man during mental labor by the speed and accuracy of different psychological processes that are based on the corresponding reflex system, the dynamic work stereotype. One can obtain the most informative data about the functional state of a worker by studying such mental functions as attention, logical thinking, memory and perception of stimuli.

To test attention, the subject is shown, for example, small tables in which different letters of the same size are placed at equal distances from one another. The standard table used in the laboratory of industrial physiology at the Scientific Research Institute of Industrial Hygiene and Occupational Diseases of the USSR Academy of Medical Sciences consists of four text groups, with five lines in each. The number of similar letters on the lines differs, but total number in each group is 30. The subject is asked to strike out one of several letters, and a record is kept of the number of incorrectly cancelled letters and time spent to perform this assignment.

The method of Grunbaum, as modified by S. A. Kosilov, can be used to test accuracy and speed of logical thinking. This method is based on the conception of the thinking process as expounding and testing hypotheses, and of going up from less probable to more probable hypotheses. When using this method, the subject is asked to find the lowest of the two-digit numbers in the table (the table may have 16 or 25 numbers), after which the presence and number of errors, and speed of problem solving are recorded. It is assumed that the subject, having begun to examine the table with some number, assesses the probability of the hypothesis that this is the sought number. He becomes convinced that the probability of this hypothesis is too low (1/16 or, if the larger table is used, 1/25). He then compares this number to some other number and finds that one is greater than the other. Thus he concludes that the number that was greater could not be the one sought, that the latter is among the remaining numbers, and the probability that the sought number is one of those he compared became higher, i.e., 1/15 or 1/24. Continuing such comparisons, the subject comes to the last pair of numbers. The probability that one of them is the

*Fitness for work, competence.

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one he is searching for is 1/2, but after determining that one of these numbers has a greater value, the probability of the hypothesis that the remaining number is the one he is searching for equals 1.

Of course, this process of logical thinking can be very rapid, and it is not necessarily completely reflected in the subject's awareness. The simplicity of the task put to the subject precludes the influence of some special knowledge and prior preparation.

The following method was used to test memory span ["volume"] in representatives of mental labor: a set of 50 one- and two-syllable words was made up; the words were numbered, then numbers of the words in the initial set were selected in random order and series of seven words each were formed; the series of words were recorded on tape every 15 s, and the interval between words, which was set by a metronome, constituted 1 s; before the test, the subject was shown the original set of words, he listened to each series of words on the tape and immediately repeated it, after which his capacity to reproduce in memory the presented words was evaluated. The mean volume of memory was calculated using the following formula:

$$\bar{V}=\frac{1}{n}\sum_{i=1}^{n}V_i,$$

where $\bar{V}$ is the coefficient of memory span; n is the number of tests; V_i is the number of words correctly repeated in the ith series of tests.

To determine the scatter of values of memory span, variance was calculated:

$$D_v=\frac{1}{(n-1)}\sum_{i=1}^{n}(V_i-\bar{V})^2.$$

Accuracy and speed of visual perception can be determined with the use of a tachistoscope. The simplest tachistoscope model (of Nechayev) consists of a plate painted black that is attached to a stand. In the middle of the plate there is a slot for exposure of visual stimuli. Using a device on the back wall of the plate, visual stimuli are shown through the tachistoscope slot at different speeds (combinations of letters having no meaning, Landolt rings, etc.), and speed of discrimination is recorded.

As shown by the results of using these psychological techniques in physiological studies of work processes, they can be quite useful, provided they

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are combined with methods that permit more accurate consideration of changes in functional state of the higher branches of the central nervous system.

The dynamics of higher nervous activity in man and formation of conditioned verbal-motor reflexes inherent in man are studied by means of the motor method with verbal reinforcement of A. G. Ivanov-Smolenskiy.[108] A modification of this method, which was developed at the Institute of Industrial Hygiene and Occupational Diseases, USSR Academy of Medical Sciences,[109] consists of a device to deliver photic and sonic stimuli, a membrane, depression of which fixes perception of the stimulus, recording instruments and control console. Photic and sonic signals (stimuli) are delivered by means of signal buttons situated on the control console. Upon appearance of a conditioned signal, the subject must depress the membrane. In view of the fact that mental labor involves a load mainly on the second signaling system, this technique develops conditioned reflexes not only to physical stimuli differing in force, but to their verbal designations. At first, each signal is accompanied by the word "depress." If the subject then depresses the membrane before the "depress" command, which is indicative of formation of a conditioned association, thereafter, following such a reaction, reinforcement of the stimulus is given in the form of the word "correct."

This method can be used to examine so-called force correlations between conditioned stimuli varying in intensity and conditioned reactions to them. As a rule, the greater the physical force of a conditioned stimulus, the greater the conditioned reaction. If a predominant inhibitory process arises, normal relations between force of the stimulus and reflex reaction change, and one observes the phases of hypnotic inhibition: equalizing, paradoxical and inhibitory. To determine lability of cortical processes, one examines extinction and restoration of the conditioned reflex, development of differentiation inhibition and change of differentiation stimulus to a positive one. To study extinction and restoration of a conditioned reflex, a stable conditioned reflex in response to a specific conditioned stimulus is first developed. Then this reflex is reproduced many times without reinforcement, and thus it is extinguished. The parameter of stability of extinction is a state when 10-fold delivery of a conditioned stimulus elicits a zero effect. After this, the extinct reflex is restored by means of reinforcement of the stimulus with the words "depress" and "correct." The number of reinforcements with the word "depress" required to restore an extinct reflex is one of the parameters of lability of cortical activity. The number of differentiation stimuli alternating with positive ones (i.e., those to which one must react) required to fix differentiation inhibition can also be considered a parameter of speed of onset and force of the inhibitory process. After the change from a differentiation to positive stimulus (after 5 deliveries thereof between positive stimuli elicited a zero effect), we began to change negative stimuli into positive ones. The number of reinforcements of a negative stimulus required to make the change is another parameter of the speed of appearance of the main nervous processes in the cerebral cortex. This method can also be used to

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get an idea about the nature of interaction between the first and second signaling systems during the work process.

By delivering stimuli varying in intensity, which affect primarily the first signaling system, and verbal designations corresponding to these stimuli, we can test the force relations in the responses to stimuli. A wide difference between responses to strong and weak stimuli is indicative of a good condition of the signaling system to which the conditioned stimulus is directly addressed. This methodological procedure can help determine which signaling system bears the predominant work load, to define the conditions of constant interaction of signaling systems and regulatory influence of the second signaling system on the function of the first.

Summing up the existing experimental data, one can define the scheme of gradual change in dynamics of higher nervous activity during prolonged and intense mental work. The initial change in dynamics of higher nervous activity is manifested by impairment of equilibrium between the main nervous processes due to attenuation of inhibition. Inhibition, being a less stable process, is depleted and attenuated faster during intensive work. This can be demonstrated when checking the accuracy of differentiation inhibition. For example, one can ask the subject to depress a dynamometer with a specific force, governed only by the muscular sensation, and record the magnitude of error. The error will increase with attenuation of differentiation inhibition. One can also ask the subject to depress the dynamometer in response to various stimuli, strongly (for example, with a force of 80% of the maximum level) and weakly (for example, 20% of maximum), and record the accuracy of differentiating between the exertions.

If equilibrium of the main nervous processes is impaired due to attenuation of inhibition, the excitatory process may remain strong at this time. To test the state of the excitatory process, the subject is asked to react rapidly with a muscular exertion to a photic or sonic signal. If the latency period of the subject's reaction remains unchanged, one can consider that there is no depletion of the excitatory process. Observation of subsequent changes in dynamics of higher nervous activity reveals signs of depletion of the excitatory process and, first of all, increase in latency period of motor reactions. If one continues to work in the presence of these changes in dynamics of higher nervous activity, the first phases of hypnotic inhibition may appear. Upon testing accuracy of muscular exertion, one finds signs of impairment of the law of force, consistency between force of the stimulus and reaction. All of these changes may be observed under industrial conditions by means of the dynamoreflexometer of Kosilov and Sanoyan (see Figure 11), which not only permits determination of the presence of infractions of the law of force, but demonstration of early and subsequent stages of changes in functional state of the higher branches of the central nervous system under the influence of intensive mental work. This instrument can also be used to examine such changes in the case of work involving mental actions together with manual operations.

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In industrial psychophysiology, mental actions are considered in connection with processes occurring in the morphophysiological substrate, the cerebral cortex. For this reason, researchers have always been very interested in the study of these processes in individuals engaged in various types of mental labor. With reference to impression of traces of excitation from the effects of visual stimuli, I. P. Pavlov indicated the localization of these processes in the cortex: "In the occipital lobe where, as we know, there is a special visual section, into which stimuli travel primarily from the eye and where they establish functional connections, both between themselves to form complex visual stimuli and directly into conditioned associations with various activities of the organism."[110]

Recording of electrical potentials in the cerebral cortex (electroencephalography) and analysis thereof permits tracking some processes of cortical regulation of mental labor. In industrial physiology, special attention is given to electroencephalograms of the regions of the cortex related to gnostic functions and voluntary movements, when studying mental labor. These regions include the frontal, temporal, occipital and central. The potentials developed by the brain normally constituted 100-500 μV on the surface of the cortex, whereas on the surface of the skull they constitute only 1/5-1/10th of this value. Amplifiers are used to record these potentials. The technique for recording bioelectrical potentials of the brain of an individual engaged in mental labor has been described in special manuals.[111]

The electroencephalogram can reflect two degrees of the waking state: diffuse waking state, or sensory rest, and active waking state. In the case of diffuse waking state, there is prevalence on the EEG of a rhythm of oscillations that is called the alpha rhythm (8-13 oscillations/s), and in active wakefulness there is desynchronization of rhythms: decreased amplitude of oscillations, appearance of beta rhythm (14-35 per second) and other rhythms. The study of the reaction of activation in different parts of the cerebral cortex by the reticular formation and as a result of influx of proprioceptive stimuli to the cortex and subcortical region is based on this fact.[112] With the normal type of reaction of the cerebral cortex to closing the eyes, which is inherent in most people, there is appreciable intensification of amplitude of alpha rhythm, and it becomes more regular; periods of exaltation of alpha rhythm grow longer, while periods of depression grow shorter. The normal type of cortical reaction to opening the eyes is characterized by distinct depression of alpha rhythm, particularly in the first few seconds, which signifies an activation reaction. When the functional state of the body changes (for example, increased efficiency due to "getting into the swing" and training, diminished efficiency due to fatigue), there is a change in latency period of the cortical reactions to closing and opening the eyes. The ratio of latency period of the reaction (LPR) to closing the eyes (CE) to LPR to opening the eyes (OE) is an indicator of the functional state of the brain, and it is designated as $K_{c/o}$.

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$$K_{c/o} = \frac{\text{LPR to CE}}{\text{LPR to OE}}$$

$K_{c/o}$ is greater than 1 in activated parts of the brain, and it ranges from 1 to 600 or more, reflecting heightened excitation. With $K_{c/o}$ of less than 1, one can refer to a diminished functional state, deactivation of some part of the cerebral cortex.

Comparison of energy of fast and slow oscillations of electrical potentials was proposed as the EEG indicator of the correlation between energy of excitation and inhibition in the cerebral cortex.[113] For this purpose, before the subject starts to work, a calculation is made of total bioelectrical activity with occipital-temporal recording of bioelectric potentials for 1 min. Concurrently with the tracing of cortical potentials on the electroencephalograph, a record is made using an analyzer of electrical oscillations of different frequencies: delta (1-4/s), theta (4-8/s), alpha (8-13/s), beta_1 (13-20/s) and beta_2 (20-30/s) rhythms. Then the energy of each rhythm is automatically determined on a special instrument, the integrator of cerebral action currents. Overall bioelectrical activity recorded before work is taken as 100%, then the intensity of each frequency is calculated as a percentage of total value. The difference between intensity of slow (delta + theta) and fast (beta_1 + beta_2) frequencies is taken as the quantitative expression of correlation between main nervous processes at a given time, while a change in this difference describes the dynamics of this correlation. An increase in difference is indicative of a change in correlation between the main nervous processes in the direction of inhibition, while a decrease is indicative of a change in the direction of excitation.

Thus, modern industrial psychophysiology is equipped with a set of effective methods that permit quantitative determination, at any moment of mental activity, of the state of the key physiological functions of man: formation and maintenance of the work dominanta, activation of cerebral cortex with retention of the dominanta and with compensation of occurring depletion of cortical neurons and, finally, approximation of the "efficiency limit" by nerve cells, development of phasic states of inhibition and impaired equilibrium of the main nervous processes. Data obtained by these methods make it possible to develop preventive measures to avert a decline of efficiency, development of pathological processes and onset of functional exhaustion among workers engaged in mental labor.

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CHAPTER 7. DEVELOPMENT OF WORK AND REST SCHEDULES

Demonstration of the leading elements of the dynamic work stereotype and key physiological functions associated with each form of work makes it possible to elaborate the optimum, physiologically substantiated work and rest schedule for workers in every occupation. The efficiency of the performers of some type of work changes in the course of the work day under the influence of social and biological factors. Factors of the former type (motivation of work, presence of work goal) prompts a worker to raise his work pace and consolidate his work time to the utmost, whereas those of the latter type (fatigue, onset of sensation of monotony, stress, protective inhibition) diminish efficiency and labor productivity. For this reason, it is necessary to interrupt work periodically for brief rest periods.

Physiological studies in industry revealed that the use of short breaks (5-10 min) at times preceding onset of fatigue is the most rational. These critical times are determined from the changes in parameters of key physiological functions, upon which depends primarily the stability of the reflex system of the dynamic work stereotype. Many observations are used to determine these parameters; the findings are submitted to statistical processing, and all this should aid in objective demonstration of the degree of stability of the functional system of the dynamic work stereotype and early signs of impairment thereof, indicative of onset of fatigue.

The existing methods of recording physiological processes make it possible to organize continuous recording of these processes on a working individual. Oxygenation of blood can be determined by means of an oxyhemograph. The heart rate can be recorded on an electrocardiograph or by means of a tele-electrocardiograph. Skin temperature is recorded with an electrothermograph, muscular function can be measured by means of potentiometric sensors of changes in articular angles and electromyography. Bioelectric potentials of the brain can be recorded also without interrupting the subject's work.

The use of these highly informative techniques permits in-depth examination of the patterns and processes of man's adaptation to various types of labor, as well as objective demonstration of changes in the dynamic work stereotype at any time during work.

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Special methods are also being developed in order to devise a work and rest schedule that would be rational from the psychophysiological point of view. For example, a complicated speech-motor method was used to develop a work and rest schedule for designers, in order to examine the process of formation and function of complex dominanta in them, that govern diverse psychophysiological functions. The subject was asked to react to lighting of a red lamp by depressing a button and refrain from reacting to a green light. By analyzing the reaction to the red light, determination was made of the rate of development of excitation, while accuracy and force of differentiation inhibition were determined by the reaction to the green light. Tests were also conducted with an additional condition: the subject was asked to memorize four- and six-digit numbers. The readings were taken four times per work shift: before work, before the lunch break, after lunch and at the end of the work day. Of all the experimental material obtained, we shall discuss here only the parameter of change in number of mistakes in remembering numbers. Analysis of the dynamics of this parameter revealed that there is no appreciable impairment of remembering four-digit numbers by designers in the course of the shift, with simultaneous performance of simple and more complicated speech-motor reactions, while remembering six-digit numbers presented some difficulty (Table 9). Interestingly enough, in a control series of studies of the same reactions in packers engaged in relatively light manual labor, it was found that these workers could not remember six-digit numbers against the background of motor reactions. This indicates that there is a greater intensity of processes in the second signaling system, as well as greater capacity for formation of complex dominantas and dynamic work stereotypes in designers than in packers.

Table 9. Number of mistakes in memorizing six-digit numbers

Time of test	Number of cases	Mistakes, %
Start of work day	46	6
Before lunch break	45	11
After lunch break	44	20
End of work day	46	13

According to the data in Table 9, there was significant deterioration of the ability to remember six-digit numbers with simultaneous performance of motor reactions in the course of the work day. The decline in number of mistakes at the end of the work day is attributable to an emotional upsurge related to nearing of the end of the work day.

Data concerning the dynamics of efficiency of designers in the course of the work day served as the basis for elaboration of a physiologically rational work and rest schedule for them, with the use of appropriate exercise on the job. S. S. Galeyev tested two variants of exercise during the work day for designers.[114] One of the variants consisted of gymnastics

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that included exercises from a set broadcast over radio. The other variant consisted of a specially developed set, which included exercises that required tension of a large mass of muscle groups and deep breathing, which elicit strong proprioceptive stimulation of subcortical parts of the central nervous system, intensify circulation in all muscles of the body and vessels of the head. A check revealed that the second set of exercises had the greatest physiological efficacy. This set was submitted to additional testing in various institutions, and it can be recommended for engineering and technical personnel, to be used during active breaks in the first and second half of the work day.[115]

In general, the task of characterizing experimental material obtained from studies of physiological processes is analogous to the tasks performed in an automatic control system. In automatic control practice, one must take into consideration the mistakes that arise against the background of ever-present random disturbances. To make a rational choice of design and mode parameters of a control system, one studies its reactions to continuously present random disturbances, and one compares the characteristics of stability of the system in different variants of design and operating mode. Theory of random functions is the mathematical structure for studies of stability of control systems. The specific form assumed by a random function as a result of an experiment is called the run [realization] of the random function. If we were to conduct a group of experiments on a random function, we would obtain a group, or family, of runs of this function. Nonrandom function $m_x(t)$, which equals, with each value of argument t, the mathematical expectation of the corresponding cross-section of the random function, refers to the mathematical expectation of random function $x(t)$. Nonrandom function $D_x(t)$, the value of which for each t equals dispersion [variance] of the corresponding section of the random function, refers to dispersion of random function $x(t)$: $D_x(t) = D|x(t)|$. The nonrandom function of two arguments $K_x(t, t')$, which equals, for each pair of values of t and t', the correlation moment of the corresponding sections of the random function, refers to the correlation function of random function $X(t)$: $K_x(t, t') = M|x^0(t)x^0(t')|$, where $x^0(t) = x(t) - m_x(t)$, $x^0(t') = x(t) - m_x(t')$.

With $t = t'$, the correlation function changes into dispersion of a random function.[116]

In order to find the characteristics of a random function, the recorded values of $x(t)$ are submitted in the form of a matrix (Table 10). Each line of this matrix corresponds to a specific run [realization] of the function (values of the physiological parameter in the ith subject at different points in time), while the number of columns equals the number of measurements of the physiological function in the course of a work shift.

In Table 10, the ith line contains the values of the physiological function under study in the ith subject at times t_1, t_2, ..., t_m. Symbol $x_i(t_k)$ refers to the value corresponding to the ith run (data obtained for the ith subject) at time t_k.

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Table 10. Matrix of initial statistical material

$x(t)$	t_1	t_2	.....	t_k	.....	t_l	.....	t_m
$x_1(t)$	$x_1(t_1)$	$x_1(t_2)$	.....	$x_1(t_k)$	.....	$x_1(t_l)$	.....	$x_1(t_m)$
$x_2(t)$	$x_2(t_1)$	$x_2(t_2)$	.....	$x_2(t_k)$	.....	$x_2(t_l)$	.....	$x_2(t_m)$
.....	.....	.....	.....	.....	.....	.....	.....	.....
$x_i(t)$	$x_i(t_1)$	$x_i(t_2)$	.....	$x_i(t_k)$	.....	$x_i(t_l)$	.....	$x_i(t_m)$
.....	.....	.....	.....	.....	.....	.....	.....	.....
$x_n(t)$	$x_n(t_1)$	$x_n(t_2)$	.....	$x_n(t_k)$	.....	$x_n(t_l)$	.....	$x_n(t_m)$

Mathematical expectation is found using the following formula:

$$\overset{\infty}{m}_x(t_k)=\frac{\sum_{i=1}^{n} x_i(t_k)}{n}.$$

Dispersion is found using the following formula:

$$\overset{\infty}{D}_x(t_k)=\frac{\sum_{i=1}^{n}[x_i(t_k)-m_x(t_k)]^2}{n-1}.$$

The following formula is used to calculate the correlation moments:

$$\overset{\infty}{K}_x(t_k, t_e)=\frac{\sum_{i=1}^{n}[x_i(t_k)-\overset{\infty}{m}_x(t_k)][x_i(t_e)-\overset{\infty}{m}_x(t_l)]}{n-1};$$

Ongoing estimation of mathematical expectation indicates a change in mean value (for all subjects examined) of the physiological parameter (key physiological function) in the course of the work day. The mean value

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of mathematical expectation over the work shift of a single subject reflects individual distinctions of his adaptation to work. The current [ongoing] characteristics of dispersion are indicative of the degree of deviation of physiological parameters from the mean value in the course of a work day. The mean dispersion gives us an idea about the range of fluctuations of the physiological parameter in the tested worker in relation to the mean level (mathematical expectation). The current autocorrelation function characterizes the link between its values at different times during the work shift. The more homogeneous the internal structure of the physiological function, the slower its autocorrelation curves reaches zero and the higher the steadiness [stationary state] of the process.

In order to solve such problems as determination of optimum work and rest schedule, evaluation of heaviness and intensity of labor, etc., by means of a mathematical model of development of the work dominanta in time (during the work shift, one must proceed from several simplified hypotheses concerning links between processes that affect the dynamics of efficiency. It was suggested that one proceed from the hypothesis of combined effect of two factors, getting into the swing of the work and fatigue.[117] Getting into the swing of the work is manifested by an increase in efficiency, strengthening of the dynamic work stereotype and increase in hourly productivity of labor. Fatigue diminishes efficiency, excitability and lability of nerve centers; it impairs the reflex system of the dynamic work stereotype. At each point in time, these factors have opposite effects concurrently (at the start of the work shift there is prevalence of the influence of the first factor and prevalence of the second at the end of the shift), and the key physiological functions changing proportionately to the algebraic sum of these factors (which have opposite signs). The "getting into the swing" process does not last indefinitely, and the increase in efficiency is limited to a certain maximum level. As time passes, the rate of increase in "getting into the swing" decreases. Fatigue diminishes efficiency also to a certain limit, and in particular efficiency cannot drop to less than zero. Fatigue, functioning concurrently with "getting into the swing" gradually diminishes efficiency, but it encounters resistance in the form of physiological countermeasures; the greater the fatigue, the more intensive these countermeasures are. In addition, with decline of efficiency as a result of fatigue, a worker alters somewhat the mode of his activity and intensifies nervous impulsation. As a result, there is slowing of increase in effect of fatigue as time passes. According to these theses, the following formula represents the mathematical model of variable dynamics of efficiency or variable dynamics of key physiological functions:

$$E = K_1(1 - e^{-N_1 t}) + K_2(-1 + e^{-N_2 t}),$$

where E is the value of the key physiological function at specific time in the work shift, corresponding to efficiency level; K is the maximum value of the "getting into the swing" factor; K_2 is the maximum value of the fatigue factor; N_1 is the coefficient indicating rate at which the first

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factor approaches the maximum value; N_2 is the coefficient indicating the rate at which the fatigue factor approaches the maximum value and e is the base of natural logarithms.

The validity of the above-described mathematical model was confirmed in a study of efficiency of individuals performing operations to adjustment of drills, as well as individuals packaging ice cream on a conveyer.[118]

Thus, by using this formula, it becomes possible to find the exact quantitative values of coefficients of "getting into the swing" of the work and fatigue by processing extensive experimental data pertaining to the study of physiological and industrial indicators of dynamics of efficiency.

One could create a single classification of intensity of work actions according to the criteria of fatigue and getting into the swing of the work with the extensive use of mathematical methods of studying and modeling physiological processes, and with the use of computers. Mathematical modeling, provided it is appropriately refined, will make it possible to plan work and rest schedules already at the stage of preparations for production. If the typical N_1 and N_2 for a given sector of industry are provided, by plotting from them the theoretical curve of efficiency one can determine the optimum work and rest schedule, schedule lunch and exercise breaks at the most suitable time, i.e., before the fatigue curve reaches values corresponding to considerable decline of efficiency that would be difficult to reverse.

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FOOTNOTES

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3. See: Derevyanko, Ye. A., et al. "Integral Evaluation of Fitness for Mental and Physical Labor. Methodological Recommendations," Moscow, Ekonomika, 1976.

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33. We use the adjective, "precision" for movements, the objective of which is to reach a precise result according to spatial, time and force parameters. They may be inaccurate, but at the same time remain oriented toward being accurate. See: Kosilov, S. A.; Vasyutina, A. I.; and Rigina, A. A. "On the Question of Cortical Regulation of Kinesthetic Analysis," FIZIOLOGICHESKIY ZHURNAL SSSR [Physiological Journal of the USSR], No 10, 1970, p 1329.

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38. Summation of excitation is manifested by the fact that a combination of two or several stimulations of peripheral receptors or afferent nerves induces a reflex, whereas each of these stimuli individually is not enough to induce a reflex. Successive summation occurs with interaction of stimuli entering a nerve center with short intervals between them over the same afferent nerve fibers. Spatial summation occurs under the concurrent effect of two or more stimuli on different receptors (author's note).

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40. Kosilov, S. A. "A Method of Training Regulation of Movements," TEORIYA I PRAKTIKA FIZICHESKOY KUL'TURY [Theory and Practice of Physical Culture], No 6, 1974, p 49.

41. Lability refers to the rate of onset, development and completion of excitatory processes. The gage of lability is the time interval, in which elementary physiological work is performed, i.e., a completed physiological process.

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