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Translation

INDUSTRIAL ERGONOMICS

Ed. by

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ANNOTATION

Successful development of ergonomics has been based, to a large degree, on its integrated approach to the study of the "man-machine-industrial environment" system, an approach calling for analysis of the many factors characterizing this system in action. The purpose of integrated analysis in industry is to reveal undesirable factors and to bring them in line with the requirements of ergonomics.

The book "Industrial Ergonomics" reflects the fundamental stages in the development of the mutual relationships between man and technology, the tasks of ergonomics and the methods used in ergonomic studies. The hygienic and psychophysiological criteria that must be accounted for when planning industrial equipment and organizing workplaces are analyzed.

As distinct from other monographs concerned with ergonomic solutions to questions of purely operator forms of labor, this book focuses on the compatibility of industrial equipment design with human anatomical, physiological and psychological capabilities in different industrial sectors: machine building, tube rolling, textile industry conveyor lines, leather production and haberdashery and organization of the labor of computer operators.

This monograph is intended for hygienists, occupational pathologists, physiologists and labor psychologists.

The book contains 39 tables, 85 figures and a bibliography of 91 references.

INTRODUCTION

Scientific-technical progress, growing automation and mechanization of industrial processes and introduction of new equipment into enterprises have altered the nature of labor and the nature of the mutual relationships between man and technology. As a result ergonomic research having the objective of integrated analysis of working conditions and improvement of mutual relationships in the "man-machine-industrial environment" system is acquiring increasingly greater significance with every year.

L. I. Brezhnev noted in a speech to the 16th Congress of Trade Unions that the party views reequipment of industry as the decisive means for improving working conditions and transforming all production operations into ones that are safe and comfortable to man. These are precisely the conditions that must be guaranteed to the working man in socialist society.

The main purpose of ergonomics is to create an objective environment providing conditions which would permit the process of social labor to proceed, speaking in the words of Marx, with the least expenditure of energy (by the producers), and in conditions that are most worthy of their human nature and are adequate to it.

This objective could be reached only on the condition that we create man's objective environment--that is, the technology supporting him--with reliance upon the entire system of knowledge of man and with full account of his anatomical, physiological and psychological features. This means that the objective of ergonomics is to optimize man's position in the "man-machine-industrial environment" system, to humanize technology while achieving correspondence between the design of industrial equipment and workplace organization on one hand and man's anatomical, physiological and psychological features on the other. Consequently the principle of "correspondence," which is implied by the unity of subject (man) and object (nature, technology) in labor, is the fundamental principle of ergonomics.

In the USSR, ergonomics is now developing in predominantly three directions--technical esthetics, engineering psychology and industrial ergonomics. Technical esthetics has enjoyed the greatest development in our country. Its objectives are artistic design of equipment and industrial esthetics. The main objective of engineering psychology is to study the relationship between the design of control consoles supplied to the most important national economic facilities (atomic, hydroelectric and thermal electric power plants, airports, power supply systems and so on) and the particular features of information perception and processing by operators. The objective of industrial ergonomics is to implement the principle of correspondence between the design of production equipment contained in factories, plants, mines and other enterprises and man's anatomical, physiological and psychological features. The process of gradually replacing man's production functions by technological resources has achieved special significance in the modern scientific-technical revolution. However, the success of scientific-technical progress, in addition to making labor less toilsome and eliminating manual labor, often creates conditions that can lead to violation of the "correspondence" principle. The reason for this lies in the difficulty of accounting for man's anatomical, physiological and psychological features in the design of complex modern equipment, which imposes high requirements upon man's psychophysiological characteristics. In a number of cases this is promoted by our insufficient knowledge of man's features--of his anthropometric characteristics--in application to the problems of ergonomics, his power and speed potentials, the unique features of afferent synthesis, and the laws governing information perception and processing. What we consequently observe among individuals servicing many forms of equipment is an uncomfortable working posture, exertion of too much effort, the necessity of performing a large quantity of operations and a higher volume of information to be processed. Conditions for the arisal of monotony and hypokinesia are often created. The design of industrial equipment may be brought into correspondence with human features only if we know what these features are--that is, if we account for the "human factor" in the planning and design stages.

In the long range, ergonomics will be an important means for raising the reliability, effectiveness and economy of production. However, there are still many difficulties in the path of its development, especially ones of methodological nature. They are basically associated to a great extent not with anthropometric problems of organizing the workplace but with the problems of informational interaction between man and modern complex equipment, which are also discussed in this monograph.

The materials presented in this book were obtained by colleagues of the division of labor physiology and ergonomics of the USSR Academy of Medical Sciences Scientific Research Institute of Labor Hygiene and Occupational Diseases in integrated physiological-ergonomic research on the appropriate enterprises. Some of the material was also obtained from experiments conducted when it was found necessary to simulate a particular production situation.

I. ORIGIN AND ESSENCE OF ERGONOMICS

Scientific-Technical Progress and the Origin of Ergonomics

Within 60 years, the Soviet Union has completed a tremendous technological revolution and implemented a broad program of the national economy's reequipment.

Today as never before, the progress of science and technology is most intimately associated with social progress: They interact with one another, accelerating mankind's movement toward communism.

Science is playing a continually increasing role in the life of society, transforming production, administration and the life of the individual. It is transforming more and more into a direct productive force; it is becoming embodied within new equipment and production processes, and in our knowledge of man and of his work capabilities and skills.

Before our eyes, entire industrial sectors and new forms of material production have been born of the womb of science. The reequipment of all sectors of the national economy, which is proceeding on the basis of modern scientific achievements, is accompanied by growth in the productivity and culture of labor.

Scientific labor is penetrating more and more into the sphere of material production, which is now requiring the participation of, besides laborers, a large number of scientists and specialists. We are witnessing the merger of science and production, of scientific and productive labor, which is accelerating the rate of scientific-technical progress.

Stimulating progress in engineering and technology, science has promoted introduction of ever-larger amounts of new, highly sophisticated machines and mechanisms into production. It would be sufficient to point out that just in 1977 alone, 4,000 models of new types of machines, equipment, apparatus and instruments were created in the USSR, as compared to 3,600 in 1976; moreover the USSR produced 236,000 machine tools, 569,000 tractors, 734,000 trucks, 41,500 excavators and much other equipment. Scientific-technical progress has led to formation of a number of new industrial sectors such as petrochemical, electronics, atomic energy and production of ultrahard, polymeric and other materials. Full automation and mechanization of production is a general direction of technical progress. There are now more than 60,000 mechanized flow and automatic lines, more than 15,000 fully mechanized shops and more than 3,000 fully mechanized enterprises in industry, and each year more than 6,000 flow and automated lines are being placed into operation.

One of the most important objectives of our science is to solve the theoretical problems and develop the concrete means and resources of improving control of equipment and of production, economic and social processes.

The extremely swift development of science and technological progress are transforming man's life, his leisure and, what is especially important, his labor. Introduction of the achievements of science and technology into production through mechanization and automation of production processes and through the use of programmed devices, calculating and problem-solving machines, electronic computers and automated control systems (ASU's) in production are altering the conditions and nature of man's labor. As a consequence, modern science and technology are raising a new social and philosophical problem--the relationship between "man and technology."

In addition to social and philosophical aspects, this problem also has the important biomedical aspect, which permits us to examine this problem from its narrower, biomedical aspect, namely as a "man-machine-environment" problem. In this statement of the problem, the broader concept "technology" is substituted by the narrower "machine" and, moreover, the concept "environment," which is closely associated with man and machine, is added. Thus this problem assumes a position equal with those of anthropology, physiology and labor hygiene. Here, "machine" is understood to imply "machine design," and when put together with man and environment, the resulting concept signifies working conditions, the convenience of servicing and controlling a machine. In other words the social-philsophical problem "man-technology" has now become one of optimizing the relationship between man and technology, or one of humanizing technology. This problem has acquired the special name of ergonomics.

The Greek roots of the term "ergonomics" are "ergon"--work, and "nomos"--law. V. M. Munipov (1970) explains this term as follows: Ergonomics is a science studying man's functional possibilities in labor with the purpose of creating optimum working conditions for him--that is, conditions which, while making labor highly productive and reliable, would at the same time ensure the necessary comfort to man and preserve his strength, health and efficiency. The Polish scholar Jan Rosner offers a somewhat different but similar definition: Ergonomics is an applied science having the purpose of adapting labor to man's physical and mental possibilities in order to ensure the most effective work--work which would not be hazardous to human health and which would be performed with a minimum outlay of biological resources (73). What these and a number of other definitions of ergonomics basically boil down to is that the purpose of ergonomics is to humanize labor by accounting for man's functional possibilities. In this century of scientific-technical revolution, it is no longer enough to study some single aspects of labor. The entire labor process--that is, the entire "man-machine-environment" production system--must be evaluated integrally, turning special attention to its main link--man. B. F. Lomov (1966) notes: "It is only on the condition that the characteristics of the machine and the environment are made consistent with man's characteristics that we can count on high effectiveness and reliability in the labor process, and consequently, on high labor productivity. Humanization of technology and the working environment--this is the noble principle which ergonomics has proclaimed."

If we accept the basic premise of ergonomics--adapting the objective environment (the implements of labor) and the surrounding conditions to the anatomical, physiological and psychological possibilities of man, then we could assert that the roots of ergonomics extend deep into the past. E. R. Tichauer notes: "Ergonomics is probably just as old as man himself." It could be said that when man began using stone tools, adapting them to the shape of his hand, spontaneous development of ergonomics began. In 1473 Ellenbog noted in his treatise that chemical substances and improperly designed equipment have an undesirable effect on human health. In the 17th century Ramazzini focused on the undesirable influence a strained work posture has on persons in many occupations. At the beginning of the 20th centry, in 1911, Gilbreth noted that as with the health of a laborer, the economic success of an enterprise depends on man's interaction with the environment.

Ergonomics began taking on the clearer outlines of a modern science during World War I, but the most tangible need for broadening research in ergonomics arose during World War II in connection with intense technological development. It was discovered during that period that military technology often exceeded man's psychophysiological possibilities, as a result of which it could not be utilized effectively, it tended to break down, and accidents occurred.

An integrated approach must be taken toward the entire "man-machine-environment" system with the purpose of ensuring optimum working conditions. Such an approach requires contact between the technical sciences and the science of man and his labor. In connection with this need's arisal, in 1949 a group of scientists in England representing different specialties made it their goal to study the "human factor" in the working environment, at production. Somewhat later the "ergonomic research society" was created. In the USA at that time, this problem was mainly within the province of psychology. A society to study the "human factor," which came to be called "human engineering," arose in 1957 in the USA.

The concept "ergonomics" was first suggested by the Polish natural historian V. Yastshembovskiy, who published the work "The Traits of Ergonomics--That Is, the Science of Labor" in 1857 in the weekly PRIRODA I PROMYSHLENNOST'. In our country, during the 1920's, when a rather considerable amount of attention was devoted to studying man's activity in an industrial situation, V. N. Myasishchev proposed isolating the study of labor as a special scientific discipline--ergology (the teaching on work). V. M. Bekhterev proposed calling this discipline ergonology. But this scientific direction did not enjoy adequate development in those years. Following the war, in the late 1950's, introduction of automation connected with swift development of science and technology made ergonomic research necessary. This research began developing on a new scientific foundation.

Presently ergonomic research is being conducted systematically in many of the world's countries. The bulk of it is being carried on by European countries (England, Bulgaria, Hungary, GDR, the Netherlands, Italy, Poland, Romania, FRG, France, Czechoslovakia, Switzerland, Sweden, Yugoslavia).

Ergonomics views the "man-machine-environment" system as a single whole, within which it would be inadequate to study just some one link, since all of the links interact with one another. What is needed is integrated research, conducted by different scientific disciplines. Because this system functions in specific production conditions, these conditions must be studied, all the more so because, as we know, the conditions of the production environment are determined to a significant extent by the work of machines. For example factors of the production environment such as noise at the workplace, dust and gas contaminants in the environment, and frequently the thermal factor depend on the work of machinery. If these factors exceed maximum permissible limits, they may have an undesirable influence on the body of the worker. Hence arises the need for conducting hygienic research with the purpose of eliminating this influence.

Ergonomics includes anthropometric research. Such research is necessary to ensure correspondence between the parameters of the workplace and production equipment undergoing planning on one hand and man's anthropometric and biochemical characteristics on the other. It must ensure proper design and arrangement of controls on equipment, and so on.

When planning and designing control consoles and, in particular, information displays, we must not only ensure their sensible arrangement, but we must also account for the absolute and differential sensation thresholds of the visual, auditory and other analyzers, and their capacity. All of this is necessary so that the operator would react correctly and promptly to work signals, so that the flow of incoming signals would not exceed man's psychophysiological possibilities. This problem is being worked on by specialists in engineering psychology.

The relationship between ergonomics and labor physiology is of major concern in ergonomics. There are many tasks for labor physiology to complete--evaluating the influence exerted upon workers by the correctness of workplace organization, the convenience of equipment maintenance and the effort applied to manipulate equipment controls, and determining the sensibility of work movements, the size of the physical load and the degree of nervous tension.

Artistic design, which follows ergonomic analysis of an industrial article, has important significance. The artist-designer must consider the comments and recommendations resulting from ergonomic research. The main task of artistic design is to create a machine or a machine tool which would correspond to esthetic requirements, produce positive emotions and create a good mood. And as we know, a good mood has a positive influence upon the individual's performance.

Examining some methodological problems in the development of ergonomics, V. P. Zinchenko, A. N. Leont'yev, B. F. Lomov and V. M. Munipov (1972) note that its arisal was a natural process in the development of scientific knowledge, in the course of which the sciences are undergoing not only differentiation but also integration, mutual penetration. Anthropology, physiology, psychology, labor hygiene and the technical sciences all interact in ergonomic research to solve the problems of optimizing human labor in modern production. Because so many sciences are involved, some authors (90; Roger, 1959) call ergonomics a multidisciplinary or interdisciplinary science.

Ergonomic analysis of labor does not mean duplication of individual physiological, psychological and hygienic studies. Ergonomics relies upon these sciences, it accounts for the degree of their importance in each concrete case, and it pursues its objective--ensuring optimum effectiveness in the function of the "man-machine-environment" system--on an integrated basis.

Now that a certain amount of experience has been accumulated in ergonomic research, certain qualitative changes can be discerned in the objective of ergonomics. Today, ergonomics is corrective in nature. The task of corrective ergonomics is a practical one--providing an ergonomic evaluation to some concrete "man-machine-environment" system with the purpose of raising its effectiveness. However, ergonomics is also beginning to participate in planning: It is subjecting human labor to multifactorial, integrated study with the purpose of developing integral optimum criteria to be used as a basis for planning effective "man-machine-environment" systems and ensuring the system's high productivity, precision and reliability, its correspondence to man's anatomical, physiological and psychological possibilities, the individual's minimum exertion and tiring, and a positive emotional influence upon him.

Ergonomics is presently enjoying extensive development. Conferences and symposiums on ergonomics are being conducted in our country as well as in other countries. International cooperation in ergonomics is developing effectively among socialist countries. The first International Conference of CEMA and Yugoslav Scientists and Specialists on the Problems of Ergonomics was held in Moscow in 1972. The second conference was held in 1975 in Burgas (Bulgaria), and the third was held in 1978 in Budapest.

The all-union conference "Designing Machines, Mechanisms and Equipment With Regard to the Physiological and Hygienic Criteria of Ergonomics," held in November 1969 under the sponsorship of the Council of Ministers State Committee for Science and Technology and the AUCCTU, promoted establishment of a correct understanding of the essence of ergonomics and its mutual relationships with other sciences. The resolution adopted by this conference states: "...planning and design institutes do not always consider the influence of physiological, hygienic and psychological factors when designing new machines and mechanisms. At the same time, experience shows that solution of the problems of ergonomics, which relies upon integrated research in labor hygiene, physiology and psychology, the theory of machine design and the requirements of labor safety and technical esthetics, in many ways promotes improvement of labor conditions in industry, easier labor and its greater productivity."

Technical progress and its economic impact will become increasingly more dependent on development of different sciences, including ergonomics, and on the pace and scale of introduction of its achievements into all sectors of the national economy.

The Mutual Relationships of Man and Technology--the Fundamental Problem of Ergonomics. Main Stages in the Development of These Mutual Relationships. The Tasks of Ergonomics.

It was noted above that ergonomics is usually taken to mean the mutual relationships between man and technology from the standpoint of the correspondence of the design of technical devices with man's anatomical, physiological features. From this standpoint ergonomics is a particular case of the mutual relationship between man and technology.

The mutual relationships of man and technology (from the political, economic, ergonomic and other points of view) are subordinated to the basic laws of Marxist-Leninist philosophy. These include, first of all, the law of constant development of these mutual relationships, the law of development of the subject (man) and the object (nature, technology) in the labor process, and the law of objectivization of the personality (the subject) in the result of labor--that is, "transformation of the ideal into the real," and subjectivization of the result of labor in the personality (in the subject)--that is, the law of change of the personality (the subject) itself in the process of labor.

It was mentioned above that from the standpoint of these laws, the main objective of ergonomics is to create an objective environment in which the process of social labor would proceed, using Marx' words, "with the least expenditure of energy (by the producers), and in conditions that are most worthy of their human nature and are adequate to it."*

Marx' directive could be fulfilled only on the condition that we create man's objective environment--that is, the supporting technology--with reliance upon the entire system of knowledge of man, and with full consideration of his anatomical, physiological and psychological features. This means that the task of ergonomics is to optimize man's position in the "man-machine-environment" system, to humanize technology, to achieve correspondence of the design of production equipment and the organization of workplaces with man's anatomical, physiological and psychological features. Consequently the principle of "correspondence," which is implied by the unity of the subject (man) and the object (nature, technology) in labor is the fundamental principle of ergonomics.

Ergonomics is presently developing in USSR in three directions--technical esthetics, engineering psychology and ergonomics specifically, or industrial ergonomics.

That part of ergonomics which is concerned with the grounds for hygienic, physiological and psychological requirements on the design of industrial equipment--that is, industrial ergonomics--had still not enjoyed broad development in our country. In light of the decisions of the 25th CPSU Congress, which foresee creation of new, progressive technology, the role of industrial ergonomics must grow. It is the task of industrial ergonomics to implement the principle of correspondence of the design of industrial equipment in factories, plants, mines and other enterprises with man's anatomical, physiological and psychological features.

Although ergonomics itself formed as a new scientific direction just 20-25 years ago, the mutual relationships between man and technology have a long history from the standpoint of the fundamental principle of ergonomics--the principle of "correspondence."

The diverse implements of labor used by man in his work, beginning with the rough stone implements of primitive people and ending with modern machinery, represent the implements of production which, jointly with the objects of labor--that is, jointly with that toward which man's labor is directed, make up a most important socioeconomic category--the resources of production.

Together with the people placing them in motion in the production of material blessings, the resources of production make up the productive forces. Productive forces are the most important motive and revolutionary element of production. Development of production begins with changes in productive forces, and mainly with change and development of the implements of labor. Development of the implements of labor, meanwhile, is intimately associated with development of man.

*Marks, K., "Kapital" [Capital], Vol 3, Moscow, Politizdat, 1955, p 833.

Man's origins lie somewhere in the beginning of the present Quaternary Period of the earth's history. The transition from fossilized humanoid monkeys to man proceeded through a number of intermediate beings combining the traits of monkeys and man--man-monkeys, or Pithecanthropes. Manufacture and use of the first implements of labor are associated with the Pithecanthropes, which lived, according to different sources, 2-10 million years ago. Primitive stone scrapers and drills have been found in the same strata as the bones of the Pithecanthropes. Since that time man's ancestors developed an erect posture and, as data collected by anthropologists show, it was precisely from this time that tool-using became a cause of man's swift transformation, particularly of his skull and brain structure. Thus arisal of labor was a powerful impetus to development of the brain of the first people.

Complete skeletons of adults and children of other human ancestors--the Neanderthals--were discovered in the lowest strata of cave deposits in Europe, Asia and Africa.

The Neanderthals, who lived 300,000-500,000 years ago, possessed stone and bone tools. They apparently also had wooden tools.

The first modern people are the Cro-Magnons, who lived 100,000-150,000 years ago. Their implements of labor, made from horn, bone and flint, were very diverse, and they bore carved ornamentation. The techniques used to manufacture tools and household objects were more sophisticated than those of the Neanderthals. Cro-Magnons knew how to grind and drill, and they were acquainted with pottery. They domesticated animals, and they made the first step toward farming. They lived in a tribal society. Cro-Magnons and modern man make up the species *Homo sapiens*--intelligent man.

The advent of man was one of the greatest turning points in the development of nature. This turning point occurred when man's ancestors began making tools. Man began to differ fundamentally from animals only when he began to manufacture tools, even the most simple. Some animals, monkeys for example, often use sticks to knock fruits down from trees and to defend themselves against attack. But no animal has ever made even the most unsophisticated implement of labor. The conditions of day-to-day life encouraged man's ancestors to manufacture tools. They were able to deduce from experience that sharpened stones could be used for defense or to hunt animals. The process of placing the spontaneous forces of nature under control proceeded extremely slowly in those ancient times, since the implements of labor were primitive. The first implements of labor were in a sense an artificial extension of human organs: The stone was a fist, and the stick was an outstretched arm.

As man underwent physical and mental development he was able to create more-sophisticated tools. Sticks with sharpened ends were used in hunting. Then stone tips began to be attached to the sticks. Axes, stone-tipped spears, and stone scrapers and knives appeared. These tools made the hunting of large animals and development of fishing possible.

Stone continued to be the principal tool making material for a very long time. The era dominated by stone tools, which lasted hundreds of millennia, is called the Stone Age. It was not until later that man learned to make tools from naturally occurring metals, beginning with copper. Being a soft metal, however, copper did not enjoy broad use in tool making. Consequently tools began to be made of bronze (an alloy of copper and tin) and, finally, iron. In correspondence with this, the Stone Age was followed by the Bronze Age, and then the Iron Age. The earliest signs of pro-Asian copper smelting have been traced back to the 5th-4th millennium B.C. Copper smelting appeared in South and Central Europe in about the 3d-2d millennium B.C. The oldest traces of bronze, which were found in Mesopotamia, date back to the 4th millennium B.C. The earliest traces of iron smelting were discovered in Egypt: They date back prior to 1500 B.C. The Iron Age began in West Europe about 1000 B.C.

The transition from stone to metal tools significantly broadened the limits of human labor. Invention of the blacksmith's bellows made manufacture of iron tools of unprecented strength possible. The iron axe made it possible to clear trees and brush from farmland. The wooden plow with an iron plowshare permitted development of relatively large areas of land. All of this promoted arisal of social division of labor, separation of the craftsman from the farmer, which brought about production directly for the purposes of barter.

Man's first tools were a simple "extension" of human hands. Many tools used today are also an "extension" of natural human organs. From this standpoint these tools fully satisfy the principle of "correspondence." However, as the transition proceeded from individual creation of tools for personal use to mass production of tools for barter, the possibility for making tools correspond to individual human features dwindled more and more. A fundamentally new factor came into being in the mutual relationships between man and technology following transformation of hand tools into machines. The most important unique feature of the latter is that they are less an "extension" of natural human organs and more a substitute for them. Marx said: "Invention of a swivel support marked creation of a mechanical device which replaced not some particular tool but man's hand itself."* This substitution of the hand by a machine represents objectivization of the subject's natural powers; at the same time, penetration of the object into the environment of the subject in a sense comes to completion in the machine. Transition to mechanical industry marked a complete technological revolution in production.

The propulsive power of the first machines was man himself or working animals; then appeared machines which were brought into motion by a water engine. The mechanical loom was invented in 1785, fully displacing hand weaving by the middle of the 19th century. The first textile factories were built on the banks of rivers, and the machines were placed into motion by water wheels. After the steam engine was developed, ways to apply it in transportation were found. The first steam locomotive was created in the USA in 1807, and the first railroad was built in England in 1825. By this time mechanical hammers, presses and machine tools--lathes, milling machines, drills--were invented. New industrial sectors came into being--machine building and metallurgy. Steam turbines were created in the 1880's. A new type of engine was invented--the internal combustion engine, first the gas engine (1887) and then one using liquid fuel--the diesel engine (1893). A new powerful force came into being in the late 19th century--electricity. Machines meant mechanization of labor. Use of machines facilitated tremendous growth of labor productivity and reduction of the cost of goods. Processing an identical quantity of cotton into yarn with a spinning machine required 180 times less working time in the 19th century than did hand spinning.

*Marks, K., "Kapital," Vol 1, Moscow, Politizdat, 1955, p 391.

The process of gradual substitution of natural human functions by technological resources attained special significance in the present scientific-technical revolution. Introduction of control consoles during the scientific-technical revolution has imparted a new quality to the mutual relationships between man and technology--the possibility for separating production control from production processes and replacing direct observation of a production process by observation of warning systems on a control console. When computers are used, it is also unnecessary to observe warning devices, because the computer can analyze the incoming signals and transmit the appropriate instructions to working organs. Such separation of the operator from the real course of a production process, its substitution by a system of codes, means that the operator acts, in the opinion of psychologists, concurrently in a real world and in an artificial world--one of signs, codes, models and symbols. He is deprived of the possibility for directly perceiving the objects under his control, inasmuch as they are separated from him in space or their direct observation is hazardous. The operator senses fully real responsibility and undergoes fully real emotional experiences, but his states are the product not of the real world, acting directly upon the operator, but rather a certain information model of this world. Every model, especially a meager, simple one created with the assistance of various resources of expression--form, color, symbolism, possesses some degree of uncertainty. In the end, an operator working on a one-to-one basis with an information model adapts himself to the model and ceases to perceive it objectively--that is, as a model of the real world, and he begins to perceive it as the object of his activity. Sometimes this may result in substitution of real motivation by feigned motivation, in loss of alertness, and in apathy.

As a result the activity of an operator in modern automated control systems cannot satisfy the efficiency and precision requirements. The main reason for this is that information models are structured on the basis of the logic of the realities they reflect, and not on the basis of the sort of activity the operator engages in with these realities--that is, to put it another way, not in correspondence with his physiology and psychology. All of this creates new problems in adapting the labor of an operator.

Moreover computer functions are now beginning to penetrate into the subjective domain--the human domain, the domain of the physiological processes of higher nervous activity. In other words the computer objectivizes certain "mechanisms" of human thinking, such that it is becoming capable of replacing, and is already successfully replacing, some of the former's manifestations.

A most important conclusion connected with this is that if information models are to satisfy this highly important requirement of the "correspondence" principle, research will have to be conducted on the objective structure of operator activity--research that must be placed at the basis of the design of information models.

The grounds for subsequent development of ergonomics are substantiated in decisions of the 24th and 25th CPSU congresses, which have posed the task of creating and introducing fundamentally new tools, materials and technical processes superior in their technical-economic indicators to the best Soviet and world models, and the task of replacing manual labor by machines on a broad scale. In terms of labor specifically, the task is to improve working conditions further. Because the documents of the 24th and 25th CPSU congresses link acceleration of the rate of technological progress in all sectors of the national economy with improvement of working conditions, we will have to expand research aimed at optimizing man's position in the "man-machine" system in application to the conditions in different industrial sectors, and primarily in metallurgy, chemistry, mining industry, power engineering, machine building and so on.

The proceedings of the all-union conference "Designing Machines, Mechanisms and Equipment With Regard to the Physiological and Hygienic Criteria of Ergonomics" developed these guidelines further by formulating the following basic requirements on industrial ergonomics.*

1. Machines and industrial equipment must be designed in such a way that they would not be a source of unfavorable sanitary-hygienic working conditions--that is, their design must correspond to the hygienic requirements in terms of maintaining the sanitary-hygienic working conditions of the workplace at the level of the standards established by public health legislation.

2. Machines and industrial equipment must be designed in such a way that they would permit maintenance in comfortable work postures, and ensure that the efforts exerted and the trajectories, speeds and quantities of joint movements would be within physiologically permissible limits. The requirements of industrial ergonomics also include those stemming from normal operation of human senses--for example, physiologically substantiated angles of vision, levels of signal intensity and volumes of perceived and processed production information. What this means concretely is that equipment design must correspond to the anatomical, physiological and psychological features of the structure and function of man's organs and body.

These are the premises that have been placed at the basis of research conducted by industrial ergonomics in various sectors of industry, and at the basis of the accumulation of scientific data to be used to form the content of industrial ergonomics.

The "Ergonomic System" Concept. Classification of Intrasystemic Relationships.

It was shown in the previous section that the mutual relationships between man and technology have been so closely related and interdependent with all stages of historical development that they now form a single system which, from the standpoint of necessary correspondence of industrial equipment and the design concepts it embodies with man's anatomical, physiological and psychological features, may be referred to as an "ergonomic system." The concept "ergonomic system" means that man, using a particular implement of labor or servicing a particular piece of industrial equipment, becomes a link in a "man-tool" or "man-machine" system, or of a "man-technology" system in general.

The inseparability and unity of this system stem from the fact that without man, no tools and no production equipment would be possible, that tools arose simultaneously with man, and developed together with him.

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*Scientific Council on the Problem "Labor Protection" under the USSR Council of Ministers State Committee for Science and Technology and the AUCCTU. 1971.

Thus the ergonomic system is one of the most important concepts (principles) of ergonomics.

Constant development of the ergonomic system, which we traced in the previous section and which is, moreover, not simply constant development but constant and accelerating development, is the second most important property of the ergonomic system and of ergonomics as a whole. The Stone Age, which was typified by the most primitive and the roughest implements of labor, lasted about a million years, during which time ordinary chunks of stone were transformed into nothing more than polished chunks of stone, which were then secured to sticks to make stone axes.

The Bronze Age lasted about 3,000-4,000 years, and during this time axes, knives and spears did not change in nature, remaining as they had been in their stony form, becoming only more beautiful in their ornamentation.

The Bronze Age quickly gave way to the Iron Age. In 3,000 years, the assortment of tools was basically enlarged only by the addition of farming tools--the plowshare and the sickle; nevertheless this was enough to raise the successfulness of farming dramatically. Much was added to the assortment of household utensils and military gear in the Iron Age. The 18th century--the century of the industrial revolution--provided the people of our planet with the loom, the spinning machine and the water wheel. The 19th century--the century of industrial mechanization--gave us the steam engine, the internal combustion engine, the electric motor and a number of machine tools intended for mechanical metalworking.

In just its first three-fourths, the 20th century--the century of the scientific-technical revolution--gave man radio, television, aviation, rocket technology, nuclear technology, the electronic computer, the control console, automatic lines, the conquest of space, and much, much else.

This examination truly does confirm the notion that the ergonomic system is characterized not by simple constant development, but mainly by constantly accelerating development, which is very important to an understanding of the unique features of the ergonomic system that are typical of this period of scientific-technical revolution.

The third main characteristic of the ergonomic system, mentioned in the previous section, is the principle of "correspondence" between the design features of production equipment and man's anatomical, physiological and psychological features. This was the principal feature in the characteristics of the ergonomic system throughout all stages of development of the mutual relationships between man and technology, but it acquired extremely important significance in the time of accelerated technical progress, when machine designers first addressed requirements which could not be satisfied without an exact knowledge of man's features--that is, when ergonomic requirements developed by specialists--physiologists, psychologists and hygienicists--became necessary.

An example of the need for precisely this approach can be found in the difficulties that arose in development of jet aviation. The speeds that were achieved were so great that were pilots to orient themselves on the basis of their own senses during flight, they would constantly be late in performing the needed control reactions due to the limited speed of nervous reactions.

Having defined the basic characteristics of the ergonomic system, we must now consider its content. An ergonomic system's content is defined as the list of units it contains for production purposes.

To determine the content of the ergonomic system, we must once again proceed from the historical standpoint--that is, with a consideration for the stages through which the mutual relationships between man and technology have passed. Most authors examining this question answer it from the point of view of the typical mutual relationships that have evolved in our times. In this connection N. P. Benevolenskaya (1972) points out that a number of authors (B. F. Lomov, N. V. Onopkin, M. F. Frolov, J. Rosner and others) view the ergonomic system as a two-unit system--"man-machine" or "man-technology." Many authors believe it consists of three units--"man-technology-environment" (K. K. Platonov, B. F. Lomov, V. F. Venda). N. T. Prikhod'ko introduces a fourth unit into the ergonomic system--the collective. Benevolenskaya believes the ergonomic system to consist of four units: "man--machine--environment--object of labor," or even five: "man--machine--object of labor--environment--persons involved with the system besides the operator or present within the machine's zone of action."

The correct answer to the question as to the content of an ergonomic system may be found by considering the history of the ergonomic system itself.

Considering the developmental stages which the mutual relationships between man and technology have undergone, we may presume that the content of the ergonomic system would never be established once and for all, but rather that it would change in keeping with the stages of development of the mutual relationships between man and technology. For a million years of man's existence these mutual relationships were limited to only two units--man and simple implements of labor--that is, the scraper, the axe and the spear. In this "man-tool" ergonomic system the working conditions were predetermined by the natural conditions of the habitat, and they did not depend on the quality of the tools. But even at this stage the nature of man's mutual relationships with tools depended in some respects on the properties of the object of labor--that is, on what the particular tool was applied to. Even at this stage the heaviness of the tool and the power generated by the individual depended on the sort of tree that had to be chopped down with the axe, the sort of soil that had to be worked with the primitive wooden plow, and so on. Therefore it would be more proper to include man, the implement of labor and the object of labor within the content of the ergonomic system in this early stage.

Benevolenskaya justifies the need for including the object of labor within the ergonomic system under modern conditions in the following way: The object of labor--that which we refer to as worked articles and earth, transported cargoes and so on--significantly influences the intensity and nature of factors arising in work with a machine, and in a number of cases it may itself be a source of these factors. As an example the properties of a block being riveted (the object of labor) may change the vibration level at the grip of a riveting hammer by 20 db. When coal in a seam is moistened, the amount of pressure a worker must maintain on a pneumatic drill decreases by 5-7 kg. Higher firmness of coal means not only an increase in the vibration levels and the pressure that must be applied, but also longer exposure to vibration and noise and a higher physical load. While a person working softer coal introduces the tip of his drill into it for a period of 3-4 seconds and then rests for 1-2 seconds, a person working with firmer coal alternates such 1-2 second rests with a drill working time of 15-20 seconds, which dramatically alters the structure of the operator's working time. Consequently when we subject machines to ergonomic evaluation, we must consider what the object of labor does to change the characteristics of the machine, and possibly to injure the operator.

Following creation of the metal smelting furnace, which was the source of high temperature, radiant heat, various sorts of gases and dust, besides man, the implements of labor and the object of labor, the ergonomic system came to include the "environment" as well--that is, the sum total of the conditions which are created by the system's operation and which may enter into interaction with its links, and mainly man.

In later stages of the mutual relationships between man and technology, the surrounding environment became the most important link of the ergonomic system. Regulating the state of the environment, as an inherent part of the ergonomic system, became a tremendously significant problem. Much significance was attached in such regulation to setting hygienic standards--that is, the permissible levels of environmental conditions, and to developing measures that would keep these levels within the standards.

Benevolenskaya explains inclusion of a fifth term in the ergonomic system--persons drawn into the system or present within its working zone--in the following way: "Persons drawn into the system indicated above but not connected with the control, use or maintenance of the machine represent a special group in this system. This group is divided into four levels: machine-microcollective, machine-macrocollective, machine-region, machine-population, at each of which unique mutual relationships, associations and tasks exist. As a rule the number of persons involved in this way significantly exceeds the number of operators. Research has shown that a special danger arises at the first level, where persons drawn into the system may be subjected to more-intense influence from 'machine factors' than the operator, receiving no compensation for the possible deterioration of health." We can agree completely with Benevolenskaya's ideas. Let us illustrate this with some examples. Weavers and spinners are assigned to specific looms and spinning machines in modern weaving and spinning shops. Besides the weavers and spinners, all other workers of the shop--foremen, auxiliary workers, strippers, loaders, removers--are exposed to loom and machine factors (noise, vibration). This happens because the looms and spinning machines, being firmly cemented to the shop floor, form a single oscillating and resonating system together with it. And while a weaver or a spinner experiences vibration due to direct contact with the parts of the loom or machine, all of the other shop personnel experience vibration due to contact with the floor. In chemical industry enterprises, all leaks in the joints of equipment, being sources of contaminants that spread through the air of the entire shop, also influence all of the shop personnel, and not just the opeators; in cases where these contaminants are discharged by the shop's stack into the atmosphere, the surrounding population is affected as well.

Thus we arrive at the conclusion that the ergonomic system is a complex concept. It includes man, machine, object of labor, surrounding environment, and persons drawn into the system. Figure 1 shows a diagram of the ergonomic system as defined by Benevolenskaya.

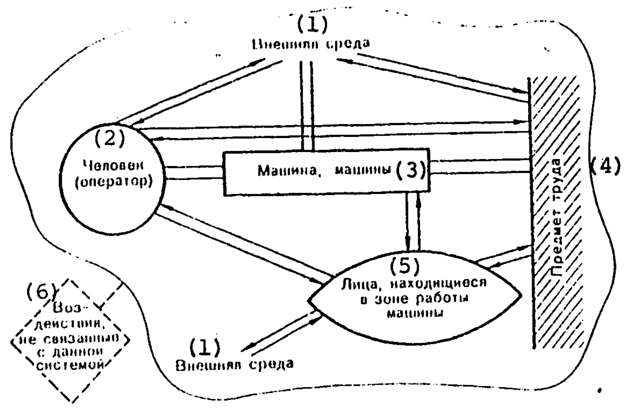


Figure 1. Associations in a "Man--Machine--Object of Labor--Environment" System

Key:

1. Environment
2. Man (operator)
3. Machine, machines
4. Object of labor
5. Persons within machine's working zone
6. Effects not associated with this system

When the content of the ergonomic system is defined in this way, it is very important to correctly classify the associations within this system. Such classification is necessary so that we could understand the internal organization of the system, determine its vulnerable links and predict its behavior in different operating conditions.

In keeping with the content of the ergonomic system, three main characteristics should be laid at the basis of this classification: the operator's associations with the machine and the object of labor, and his interaction with the working conditions.

When we study the operator's associations with the machine, we must keep in mind that these associations are maintained primarily through informational interaction between the operator and the machine. In this case, informational interaction itself accounts for the particular features of the input functions upon which transmission of information to the human senses depends, for the particular features of the control functions performed by the central nervous system and dependent upon its state, and for the particular features of the output functions, which in most cases are realized by means of man's sensomotor organs and muscular system and which also depend on their functional state.

Jan Rosner distinguishes three stages of informational interaction.

1. Perception of information either by direct observation of the production process or by observation of the readings of monitoring and measuring instruments reflecting the parameters of the production process. Perception is achieved by means of sense organs, which transmit obtained information to the individual's central nervous system. This phase of the labor process (perception of information and its transmission to the central nervous system) is within the sphere of action of physiological and psychological laws.

2. Processing (transformation) of the obtained information occurs in the central nervous system and leads to adoption of a particular decision. Little is known yet about the decision making mechanism. Not only the information entering from without (from the machine, from the environment) but also internal information influences the nature of the decision, its correctness and the swiftness with which it is adopted.

Internal information comes from the memory, which stores information and instructions received previously. In addition to information contained in the individual's memory, intuition, which influences decision making, also plays a great role.

"Stress" situations, or states of nervous tension that reflect the body's reaction to injury and shock, and psychological difficulties such as fear, a state of intense arousal and so on, play a role in information processing and decision making.

3. The last stage of the labor process is transmission of the adopted decision to operating organs and implementation of this decision. This last stage is called control, and in a "man-machine" system it is achieved by exerting an influence on the machine's controls with the purpose of making the necessary changes in the process occurring within the system. In this case the output is represented by man's operating organs, and the input is represented by the machine's controls.

Thus perception, decision making and implementation of the decision form a closed structure of interaction between man and machine in the ergonomic system. Interaction between these two basic elements of the system--machine and man--essentially consists of information transmission and control on the basis of the feedback principle.

In addition to informational interaction between operator and machine, there are other types of interaction characterized by the working posture of the operator servicing the machine, the effort expended and the speed, trajectory and quantity of movements required, as will be discussed in detail below.

A classification of intrasystemic associations must also include the associations between the operator and the object of labor and the associations between persons drawn into the system, and especially the conditions created within the system.

As far as associations between the operator and the object of labor are concerned, they are achieved through the machine, and they basically have an influence on the degree to which informational interaction is expressed or on the hardness and intensity of the work of the operators.

Before we can classify intrasystemic associations subjectively, we must analyze them correctly. Such analysis begins with description of the system and subsequent application of hygienic, phsyiological, psychological and special ergonomic methods of analysis. This will be discussed in greater detail in the course of the material's presentation.

II. METHODS OF STUDYING AN ERGONOMIC SYSTEM

As follows from our analysis of the content of an ergonomic system and the classification of intrasystemic associations, the methods of ergonomic analysis must be aimed at establishing how man is influenced by the factors arising within the ergonomic system, such that recommendations aimed at optimizing man's position in the system could be developed. Specifically, the analysis methods must be aimed at: studying the working conditions and revealing the design shortcomings of the production equipment that worsen the working conditions, such that by their elimination the working conditions could be improved; evaluating workplace organization from the standpoint of ensuring a normal work posture and permissible speeds, trajectories and quantities of movements and efforts necessary to service the production equipment; studying informational interaction between the operator and machine.

Thus the methods of studying ergonomic systems include hygienic methods concerned with the working conditions, physiological methods used to study physiological state, anthropometric methods to determine the body's anatomical dimensions and special ergonomic methods to study the design features of serviced equipment.

Hygienic methods used in ergonomics are essentially the same used in conventional hygienic research.

Physiological methods, which are used to study physiological state, are also the same ones employed in research on labor physiology, the one difference being that in ergonomic research, more attention must be devoted to procedures for evaluating the state of the motor apparatus, the nervous system and the sense organs. In this connection hygienic and physiological methods will not be described in this section.

Anthropometric Methods of Analysis

Special instruments are used with anthropometric methods of analysis--Martin's anthropometer and an angle gage. Many tables of anthropometric data are available. They contain more than 300 different indicators pertaining to different anatomical dimensions of the human body. In practical ergonomic research, however, only a small part of the existing anthropometric data are used to evaluate the correspondence of workplace dimensions and working instruments to the dimensions of the human body. Standard 22315 was proposed in the GDR for this purpose. It includes 12 anthropometric indicators, namely body height, shoulder height, thigh length, knee height, thigh height, upper arm length, forearm length, width at the shoulders, seated body height, seated eye level, seated shoulder height and standing eye level.

Having critically evaluated this standard, the ergonomics laboratory of the USSR Academy of Medical Sciences Institute of Labor Hygiene and Occupational Diseases developed its own proposals for a standard on anthropometric indicators used in ergonomics. These proposals are represented in tables 1-3 and in figures 2 and 3.

Table 1. Anthropometric Dimensions Used in Ergonomics, in Centimeters

		USSR		GDR		
Posture	Measured Dimensions	Men M±σ	Women M±σ	Men M	Women M	Use in Ergonomics
Standing	Body length (height)	167.8±5.8	156.7±5.7	171.5	159.8	To determine tool height for work while standing, and the height of the work space
	Body length with up-stretched arm	213.8±8.4	198.1±7.6	-	-	To determine vertical reach with the purpose of locating controls
	Deltoid shoulder width	44.6±2.2	41.8±2.4	-	-	To determine workplace dimensions
	Length of arm stretched forward*	64.2±3.3	59.3±3.1	-	-	To determine forward reach
	Length of arm stretched to the side*	62.2±3.3	56.8±3.0	-	-	"
	Shoulder length	32.7±1.7	30.2±1.6	35.5	32.7	To determine height of controls and height of work surface
	Leg length	90.1±4.3	83.5±4.1	92.8	85.8	"
	Thigh length	-	-	44.4	43.0	"
	Standing eye level	155.9±5.8	145.8±5.5	159.8	149.1	To determine height of work surface and location of displays, and the field of view
	Shoulder point height	137.3±5.5	128.1±5.2	141.7	132.1	To determine height of work surface and height of controls

*With hand clenched into a fist (grasping position).

	Palm point height	51.8	3.5	48.3	3.6	-	-	To determine grasping zone
Sitting	Body length	130.9	4.3	121.1	4.5	-	-	For machine operation and other jobs, selection of cab height in machines, combines, tractors, etc.
	Height of eyes above floor	118.0	4.3	109.5	4.2	-	-	To determine height of work surface and locations of warning signals and displays
	Height of shoulder above floor	100.8	4.2	92.9	4.1	-	-	To determine height of work surface and lever control zone
	Height of elbow above floor	65.4	3.3	605.	3.5	-	-	"
	Knee height	50.6	2.4	46.7	2.4	-	-	To determine height of work chair
	Body length above seat	88.7	3.1	84.1	3.0	88.4	84.3	To determine height of machine tools, controls, displays
	Height of eyes above seat	76.9	3.0	72.5	2.8	772.	73.6	To locate controls and displays, to determine height of work surface
	Height of shoulder above seat	58.6	2.7	56.0	2.7	59.1	56.6	To locate controls, to determine height of work surface
	Height of elbow above seat	23.2	2.5	23.5	2.5	-	-	To locate elbow rests, to determine workplace height
	Length of forearm*	36.4	2.0	33.4	1.8	35.5	32.0	To determine forward reach and workplace dimensions
	Length of outstretched arm	104.2	4.8	98.3	4.7	-	-	To locate manual controls
	Thigh length	59.0	2.7	56.8	2.8	-	-	To determine seat dimensions

*With hand clenched into a fist (grasping position).

Table 2. Basic Dimensions of Human Hand

(1) Точки на рис. 3	Размер, см (2)		
	наибольший (3)	(4) средний	(5) наименьший
А	20	18,5	17
Б	9	8,2	7,6
В	12,1	11,2	9,9
Г	7,8	7,3	6,8
Д	7,3	6,6	5,8
Е	12,1	11,2	9,9

Note: When protective gloves are worn, the width and thickness of the hand are increased by 1-1.5 cm.

Key:
1. Points on Figure 3
2. Dimension, cm
3. Greatest
4. Average
5. Least

Table 3. Basic Dimensions of the Human Head

(1) Точки на рис. 3	Размер, см (2)		
	(3) наибольший	(4) средний	(5) наименьший
А	23,3	21,8	18,5
Б	16,5	14,8	13,1
В	20,2	18,8	16,8
Г	--	11,2	--
Д	13,9	12	9,7
И	13	10,8	8,2
К	--	6,5--6,8	--
Л	7,6	6,3	4,9
М	--	12,5	--
Н	13,4	11,4	10

Key:
1. Points on Figure 3
2. Dimension, cm
3. Greatest
4. Average
5. Least

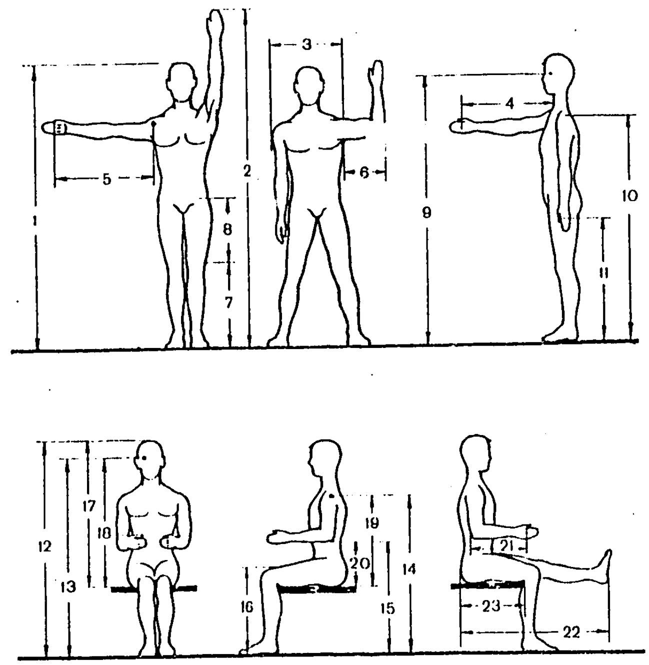


Figure 2. Human Body Dimensions Needed in Ergonomics (See Table 1)

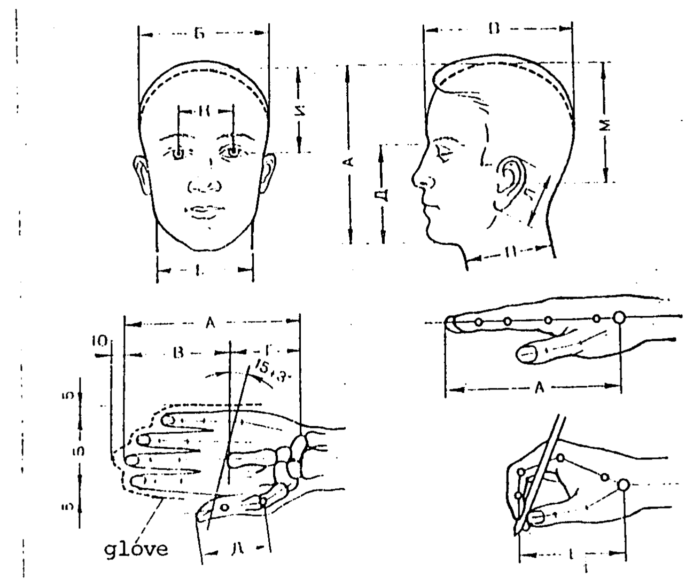


Figure 3. Basic Dimensions of the Head and Hand (See Tables 2 and 3)

As we can see from these data, use of 28 anthropometric indicators for the torso, six for the hands and 10 for the head (44 anthropometric indicators in all) is foreseen for the purposes of ergonomics. Concrete uses of each anthropometric indicator for the torso are stated in Table 1.

Every anthropometric characteristic is known to be a random variable having a normal distribution represented by the gaussian curve. Knowing the probability distribution and the average of a characteristic (M) and the standard deviation (σ), we can determine the percentage of people for whom that anthropometric characteristic fits within in a given interval.

For example 99.7 percent of all characteristics having a normal distribution, or to put the same thing in another way, 99.7 percent of all people fall within the $M\pm3\sigma$ interval. The following relationships are valid for a normal distribution:

The interval	$M\pm2\sigma$	corresponds to	95%
"	$M\pm1.65\sigma$	"	90%
"	$M\pm1.15\sigma$	"	75%
"	$M\pm1\sigma$	"	68%
"	$M\pm0.67\sigma$	"	50%
"	$M\pm0.32\sigma$	"	25%

Using these data, in each case we could calculate the percentage of people having dimensions in keeping with a particular structure (a seat, a cab, a console, etc.).

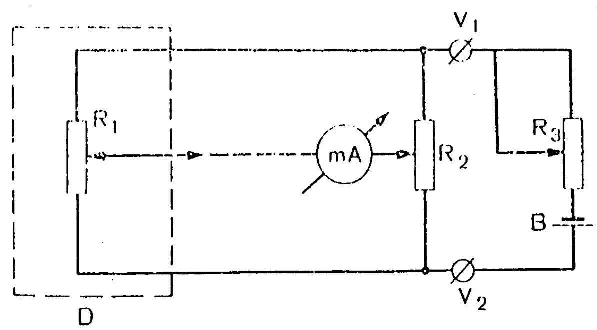
The methods of special ergonomic analysis may be subdivided into different forms depending on their purpose. It should be kept in mind, however, that special ergonomic methods of analysis are still in their developmental stage. The greatest difficulties lie in evaluating the workplaces of machines such as tractors and combines, and cabs housing control consoles. The difficulties encountered here by ergonomists will be discussed below.

The dimensions of equipment are given as metric and angular measurements to permit assessment of their correspondence with the anatomical dimensions of the human body. This is easily done for a simple office desk or chair. However, ergonomics has yet to scientifically substantiate the choice of methods for determining the linear and angular parameters pertaining to the location of controls and the work seat, and the dimensions and shape of levers, pedals and so on, for example in tractor cabs.

Methods of Determining the Quantity of Movements, Their Speeds and Trajectories

There are considerable difficulties in evaluating the speeds, trajectories and numbers of movements made by the arms or legs when servicing a particular piece of production equipment. What we use here are tensometric (recording force and time characteristics) and potentiometric sensors (recording biomechanical parameters and movements of controls), requiring employment of special amplifiers and recorders.

We can describe as an example a system for mechanical time-and-motion studies proposed by P. I. Gumener. It uses a rheostat sensor, contained within a bridge circuit, and a recorder (Figure 4A). The sensor consists of a variable resistor (470 ohms) one strip secured to its shaft and another to the main body of the resistor. One of the sensor strips, along which wires are secured, is fastened to the operator's shoulder, and the other is fastened to the forearm in such a way that the shaft of the variable resistor would be in line with the axis of the elbow joint (Figure 4B). Three multistranded conductors are braided into a single cable 2·meters long having a plug at its end. When the operator must be disconnected from the instrument for a short period of time, rather than removing the sensor the operator need only remove the plug from its socket. This is especially convenient when we study not all of an operator's work but only individual moments of it. The conductors leading from the sensor to the recording instrument may be of any length (20-30 meters and more). A recording N-370 or N-375 ampere voltmeter is used as the recording instrument. This instrument is simple, and it may be assembled in the laboratory from readily available components. Figure 5 shows an example of recordings made of different work operations.



A

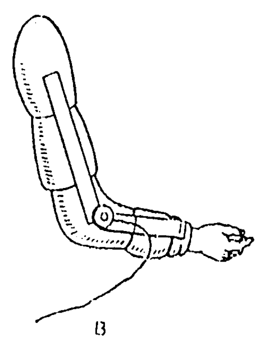


Figure 4. Circuit of an Instrument Used for Mechanical Time-and-Motion Studies: A: R_1--variable resistor (470 ohms) of the mechanographic sensor; R_2--variable resistor (470 ohms) used to balance the bridge; R_3--variable resistor used to set nominal voltage; B--battery, mA--N-370 AM recording milliampere voltmeter; D--mechanographic sensor; V_1, V_2--voltmeter terminals; B: position of sensor for recording movement mechanograms

When necessary, a multichannel system for group mechanical time-and-motion studies may easily be assembled from such single-channel systems. Such a system (Figure 6) can be used to simultaneously study several operators or record the work of several joints. A multichannel system consists of 8-14 rheostat sensors and an N-102 or N-700 loop oscilograph, which can be connected to terminals I-II, III and so on (see Figure 6). An example of a recording made during a group mechanical time-and-motion study is shown in Figure 7. In this variant of the instrument the

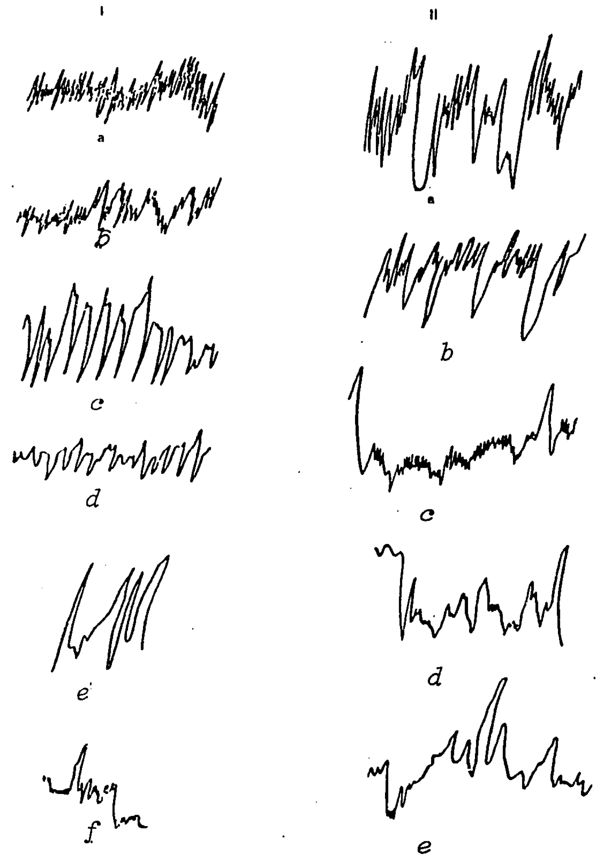


Figure 5. Mechanical Time-and-Motion Study of Work Operations in a Mechanic's Shop (I) and a Carpentry Shop (II): I--principal operations: *a*--filing; *b*,*c*--cutting; *d*--working tin with a mallet; auxiliary operations; *e*--tightening a vice; *f*--taking measurements. II--principal operations: *a*--planing; *b*--sawing; *c*--filing; auxiliary operations: *d*--sandpapering; *e*--taking measurements

mechanochronograms must be processed by hand. However, Gumener also described an instrument intended for automatic mechanochronogram recording (1967).

A tensomyographic method for determining muscle tension when working with various controls, developed by V. I. Golovan' (1972), can be used successfully to record the movements of joints and to keep track of muscles performing a movement. In this method muscle tension accompanying a natural work process is recorded by tensoresistor sensors secured to the subject's skin over the target muscles with adhesive strips. The sensors are secured firmly enough so that they would not slip over the surface of the skin, but not so firmly that they would constrain the joint's movement or

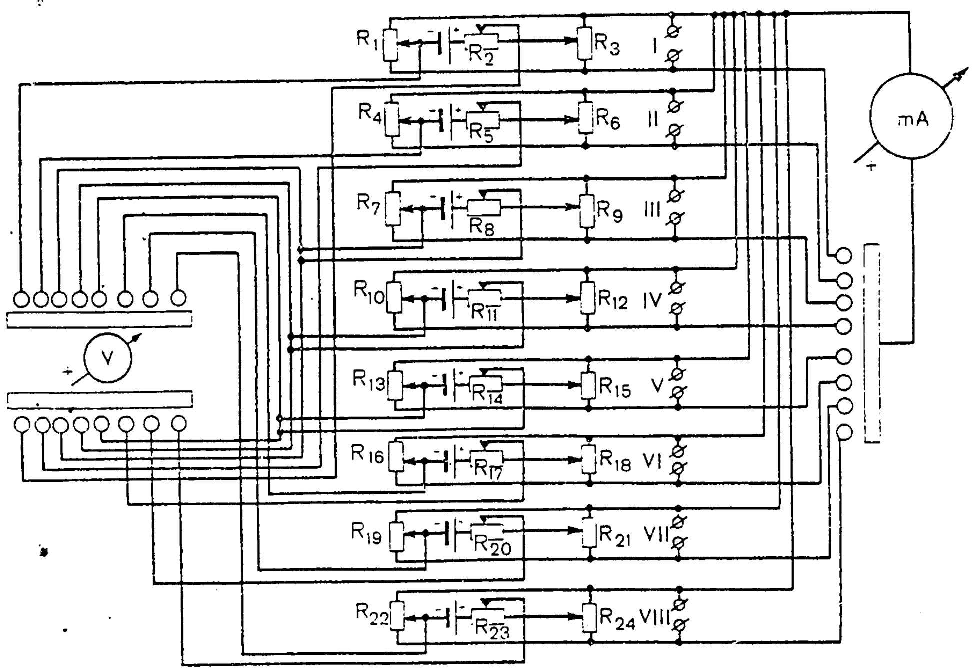


Figure 6. Diagram of the "GM-1" Instrument for Group Mechanical Time-Time-and-Motion Studies

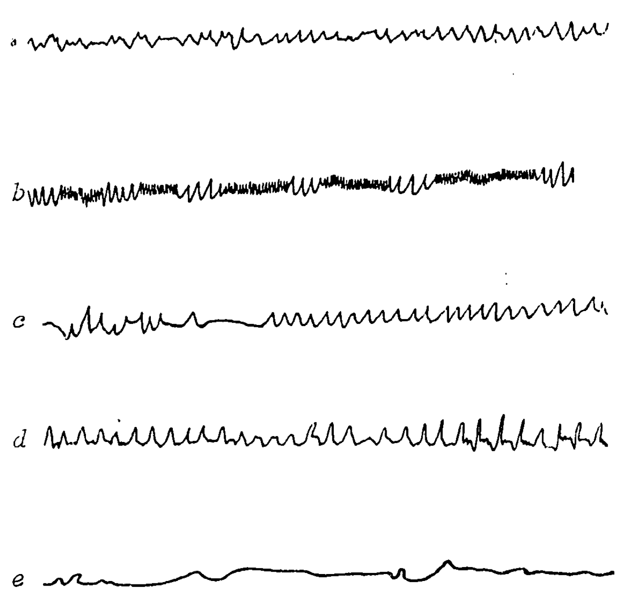


Figure 7. Group Mechanical Time-and-Motion Study: *a*--metal cutting; *b*--chopping; *c*--sawing wood; *d*--planing; *e*--measuring parts

disturb circulation in the muscle. A light cable up to 25 meters long with a plug at its end is secured to the subject's belt to permit free movement around the machine. A TA-5 amplifier is used to amplify the electric signal picked up from the strain gages. Change in voltage picked up by the strain gages is recorded by a multicomponent K-12-21 oscillograph, which is a general-purpose electromagnetic instrument capable of optical recording on photographic tape. The tensomyographic method can be used to obtain data characterizing the tension of different muscle groups and the extent of their participation in work movements, the quantity of the work done, the rhythm of movements and the dynamics of fatigue development.

Researchers making biomechanical observations on an individual in the course of ergonomic research often need to know the number of arm movements. N. A. Kokhanova and G. I. Barkhash (1972) used an ordinary pedometer for this purpose. As we know, pedometers are used to count the number of steps an individual takes. They record vertical jolts occurring while walking. Kokhanova and Barkhash adapted pedometers to record the number of arm movements in both the vertical and horizontal directions. To record horizontal movements, the pedometer's spring was removed from its post (Figure 8A*a*), as a result of which its weight (Figure 8A*b*) could make a horizontal movement which would actuate a counter. Two pedometers are fastened to the individual when the distal division of the right and left forearms must be studied. One of them is located on the backside of the forearm, and it records horizontal movements, while the other is fastened perpendicularly to the first in order to record vertical arm movement. To make it easier to secure the pedometers to the arms, they are inserted into a special holder with their reset knobs facing each other (Figure 8B). The authors used this method to record the number of arm movements made by two groups of grinders performing circular and slot grinding. The research showed that in circular grinding, the number of vertical movements made by both arms during a shift averaged 6,260 and the number of horizontal movements averaged 6,058, while with slot grinding the number of vertical movements averaged 4,063 and horizontal movements averaged 5,110. The temporal dynamics of these data are shown in Figure 8C. The results provide additional objective information on the activity of the human motor apparatus during work in the course of a shift.

Cyclography*

Cyclography permits a more-accurate biomechanical evaluation of the movements of different body joints in ergonomic research. Cyclography affords a possibility for determining all of the main biomechanical indicators of joint movement--trajectory, speed, acceleration and muscle force.

The cyclographic method essentially entails registration of point images of the movement trajectory. For this purpose lamps (from a pocket flashlight) are secured to the points of the body to be analyzed. The light of these lamps is periodically interrupted by a special device--an obturator. When motion picture photography is employed, successively taken frames assume the obturation function.

Rubber straps with sockets are the most convenient for securing the lamps to the subject's body (Figure 9). Lamps are located above the centers of the joints between

*This description is borrowed from the book "Praktikum po fiziologii truda" [Handbook on Labor Physiology] (K. S. Tochilov, Editor), Izd-vo LGU, 1970.

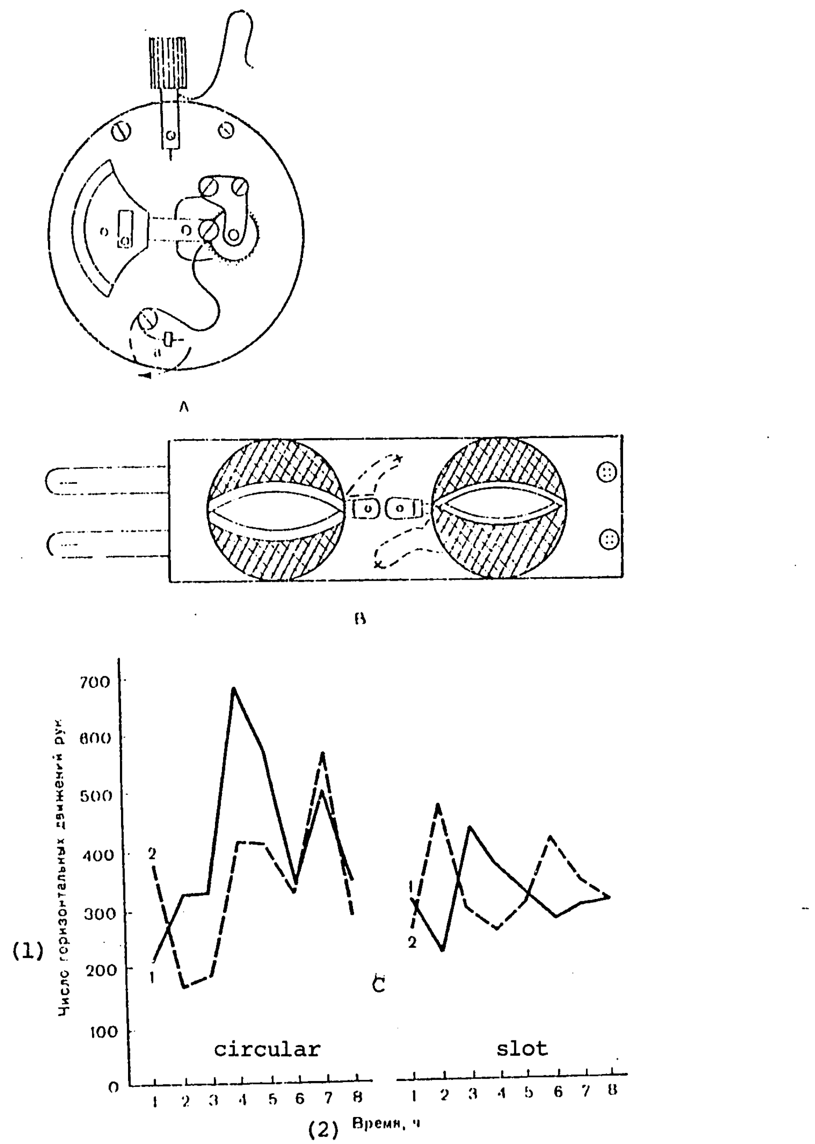


Figure 8. Using a Pedometer to Count the Number of Arm Movements: A--modification of the pedometer; B--a device for holding two pedometers; C--dynamics of the number of horizontal arm movements made by workers performing circular and slot grinding during a shift: 1--right arm; 2--left arm

Key:
1. Number of horizontal arm movements
2. Time, hr

articulating units. On the head and hands, the lamps are secured above their centers of gravity.

The obturator, which is needed to break down individual movements into phases--to obtain a chronocyclogram--is a necessary element of cyclographic recording. It is a unique sort of chronometer.

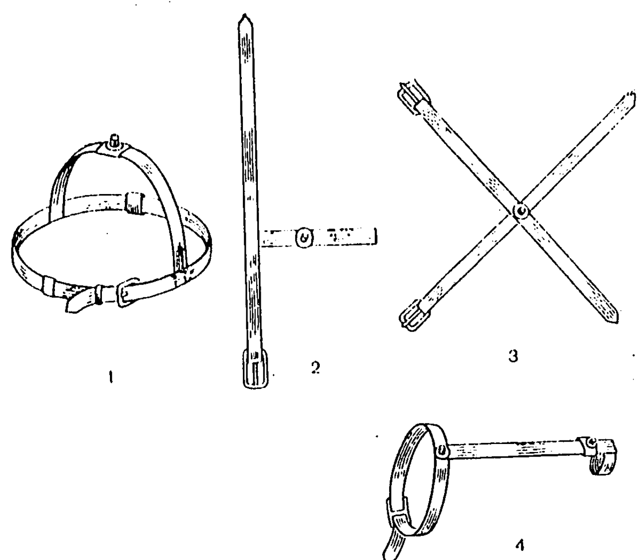


Figure 9. Strap Patterns for Different Parts of the Body: 1--for the head; 2--for the shoulder joint; 3--for the elbow joint; 4--for the wrist and for the point corresponding to the position of the hand's center of gravity.

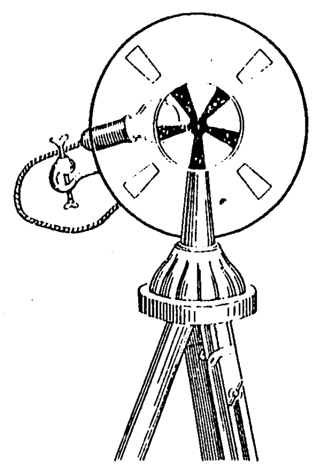


Figure 10. Obturator with Rosette and Neon Lamp

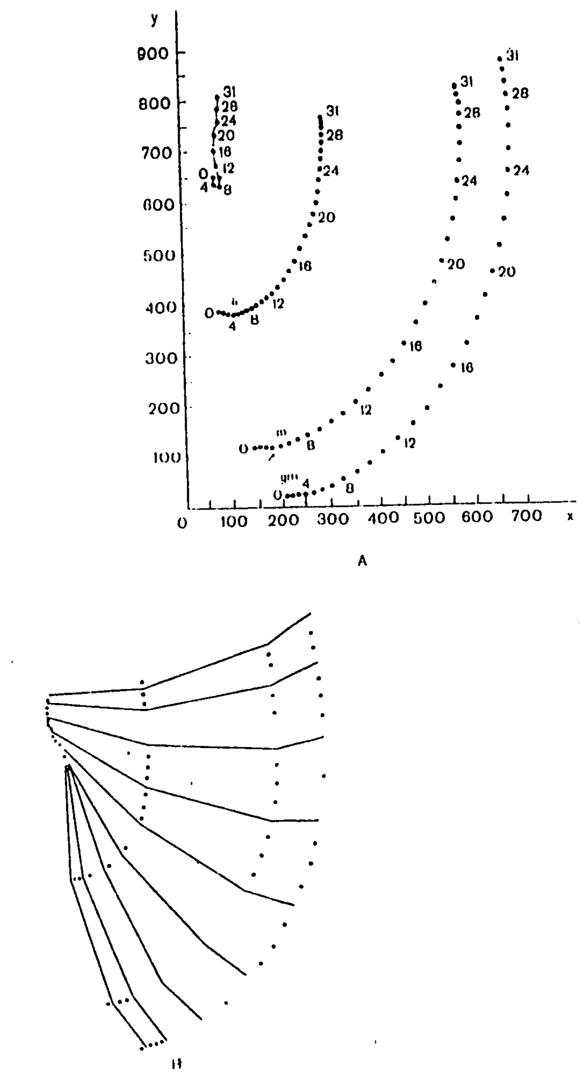


Figure 11. Photographic Measuring Template for the Rod Lifting Movement (Scale--1:5) (A); Graph Showing Successive Positions, Spaced 0.1 Sec Apart, of Arm Segments While Lifting a Rod (40 Points Are Photographed Per Second) (B)

The obturator consists of a cardboard or soft metal ring. Holes are cut in the ring symmetrically; their number can be arbitrary. The constancy of the obturator's rotation rate is monitored by a special device consisting of two parts: a small cardboard ring with rays drawn on it--the so-called rosette, and a neon lamp that illuminates the rosette (Figure 10). The ring rests on the axle of a little motor that rotates it smoothly. The obturator is placed in front of the camera's lens. Rotating, the ring of the obturator periodically covers and uncovers the lens. As a result the photographic image of the trajectory would consist of points (Figure 11A).

Constant rotation of the obturator is a mandatory recording condition. Only in this way can it be used as a chronometer, and can we precisely calculate the number of points taken by the film per unit time, which will indicate the total duration of the movement.

The rays of the rosette are always of the same size while the holes in the obturator are not: When there are four or five holes, one of them is made narrower; with eight, two are made narrower. The narrow holes are needed for synchronization of the points of different trajectories: They serve as reference points with which to establish serial numbering. The ring is seated on the same motor axle to which the obturator is secured. The device's principle of operation is based on the stroboscopic effect: In this case the rays of the rosette produce the visual effect of motionless only if the obturator is rotating at a particular speed. The rosette would appear motionless if the time for one ray of the rosette to move to the position occupied by the previous ray coincides with the time the neon lamp is on (1/50 sec). For example were the rosette to have only one ray, for that ray to appear motionless the rosette would have to make one complete revolution in the time of one flash--that is, in 1/50 sec; if there are two rays on the rosette, the time would be 2/50 sec, and so on.

Consequently the more rays there are on the rosette, the fewer revolutions the obturator would have to make to achieve a stroboscopic effect.

To determine the number of points (K) taken in 1 sec, the number of holes in the obturator must be divided by the number of rays on the rosette and multiplied by 50 (the number of times the neon lamp is interrupted in 1 sec):

$$K = \frac{d}{e} \cdot 50,$$

where d--number of holes in the obturator; e--number of rays on the rosette.

K is the principal photographic indicator because it tells us how many points the trajectory of motion is broken down into within 1 sec. Thus if $K = 40$ (for example at $d = 4$ and $e = 5$), each point would stand for 1/40 sec, and if the trajectory of the given motion is represented by 20 points, the duration of the entire movement would be 0.05 sec.

To photograph movements, the camera must be arranged in relation to the object in such a way that the image of the object would be in the center of the photograph.

The photograph must be supplied with a scale, which is why a stand supporting two lamps 50 cm apart is placed behind the subject within the plane of movement.

The procedure is as follows:

1) Set up the camera;

2) set up the obturator in front of the lens, use the rheostat to get the obturator rotating at the needed speed, and achieve the stroboscopic effect;

3) locate the distribution box in a convenient place near the experimenter;

4) have the subject put on the belt, and connect it to the distribution box;

5) prepare the subject for photographing. For this purpose secure lamps with the straps to the shoulder, elbow and wrist joints, and at the center of gravity of one of the hands in the case of profile photography;

6) measure and note down the distance between the lamps on all arm segments, using the following symbols: for the shoulder; b-a, for the forearm, a-m; for the hand, m-gm; here, b represents the lamp at the shoulder joint, a is the lamp at the elbow joint, m is the lamp on the wrist and gm is the lamp at the hand's center of gravity;

7) photograph several movements, develop the negatives, and make prints having a scale one-fifth of the actual trajectory magnitude;

8) remeasure and note down the distance between the lamps on the photographed segments of the body.

The principal document used to process the data is the photographic measuring template (see Figure 11A). It is obtained from the negative produced by projecting the cyclogram on graph paper through an enlarger.

The measuring template is obtained as follows:

1) Superimpose the scale points over the thick line on the graph paper;

2) select a scale, for example 1/5 or 1/10; consequently the distance between the scale points on the graph paper would have to be 10 or 5 cm, since the real distance was 50 cm;

3) use a thin-leaded pencil to reproduce the points representing the trajectory of movement on the graph paper;

4) number the trajectory points--the center of gravity of the hand and the centers of the wrist, elbow and shoulder joints; apply a serial number to every fourth point: 0, 4, 8 and so on (if 40 points are photographed in a second, every fourth point would represent 0.1 sec of lapsed time);

5) draw coordinates x and y on the measuring template in such a way that all points would fall between these two axes;

6) label the coordinates in their full-scale values, taking account of the scale.

> Example: If the photograph is reduced by a factor of 5 (if the scale is 1/5), the values of the coordinates would have to be increased by five times (10 mm would represent 50 mm in full scale).

In this form, the photographic measuring template is ready for use.

Using the photographic measuring template: 1. Determine the total time of movement. For this purpose the number of points taken in 1 sec must be known.

> Example: If there are 31 points on the distal trajectory (gm) and if 40 points are taken per second, the time of the movement would be 31/40 sec, or 0.775 sec. The distal trajectory is chosen because the points on the trajectories of the proximal segments may fuse together owing to low speed.

2. Determine the average rate of movement (approximately) on the distal trajectory--in this case this would be the rate of movement of the center of gravity of the hand holding the weight. A curvimeter or a piece of thread can be used to measure the trajectory of the hand's center of gravity. The obtained value is converted to the actual value in correspondence with the scale, and it is divided by the total time of the movement.

> Example: If the trajectory of the hand's center of gravity is measured to be 139 cm on a measuring template with a scale of 1/5 and if the time of movement was 31/40 sec, the actual trajectory would be 695 mm and the average speed would be

$$\frac{695\times40}{31} = 900 \text{ mm/sec.}$$

3. Graph the successive positions of the body segments. For this purpose transfer the numbered points of all trajectories from the measuring template to tracing paper and connect them with straight lines (Figure 11B). If the number of points taken in 1 second is 40, then it would be best to connect every fourth point of all segments on the graph. Then we would have a 0.1 sec interval between each position of the arm as it lifts the rod.

4. Determine the angles and graph the movement of the wrist and elbow joints. By doing so, we can establish whether or not the movement had been performed in accordance with the instructions (for example the elbow and wrist angles of the outstretched hands had to be 180° as they lifted the rod). This determination is made from the graph of successive segment positions. For this purpose the center of a protractor is located on the apex of the angle to be measured and its straight side is aligned with the axis fo the proximal segment. The obtained data are used to plot a graph (Figure 12A): The serial numbers of the points (that is, time) are plotted on the abscissa and the angles are plotted in degrees on the ordinate.

5. Check the coordinates of points on the trajectory of gm; the trajectory of gm is chosen because the kinematic characteristics of a movement (speed and acceleration) best characterize this movement in relation to its distal trajectory. Determine the coordinates (x and y) of each point on the photographic measuring template. The coordinates are measured with an accuracy of up to 5 mm actual value at a 1/5 scale (1 mm on the measuring template). Enter the data in the table. These data will show how the movement progressed in every fortieth of a second.

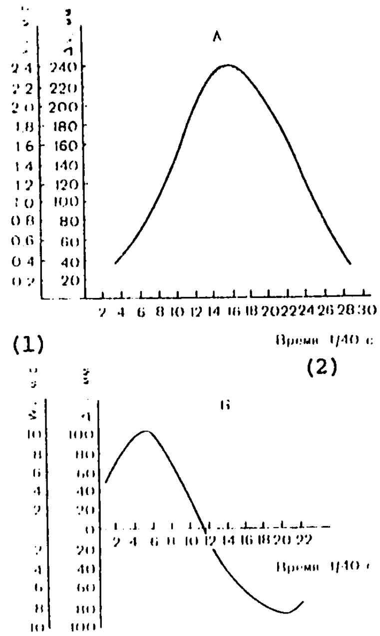


Figure 12. Parametric Graph of the First Differences and Speeds in Relation to Component y (A). Parametric Graph of Second Differences and Accelerations in Relation to Component y (B)

Key:
1. Meters/sec
2. Time, 1/40 sec

6. Calculate the speeds in relation to components x and y. For this purpose find the differences between the coordinates of the points (the so-called first differences--Δ'). The first differences are calculated for an interval of four points--that is, the coordinate of point 0 is subtracted from the coordinate of point 4, and the result is written, together with its sign, opposite the coordinate of point 2; next the data for point 1 are subtracted from the coordinate of point 5, and this result is written opposite point 3, and so on until completion. In this case it would be convenient to use a template (see Figure 12A). The data are entered into a table, and then on a graph of the first differences in relation to the movement component (x and y).

The first differences (Δ') are converted to speed in relation to, for example, component y (V_y) using the following formula:

$$V_y = \frac{\Delta' y \gamma}{\beta \times 1000} \text{ m/sec},$$

where β--interval between point coordinates (4 in our case); γ--number of points in 1 sec (40 in our case); 1,000--for conversion of millimeters into meters.

Example: If the first difference (Δ') is 20 mm, then the speed in relation to movement component y at the given moment would be:

$$V_y = \frac{20 \times 40}{4 \times 1000} = 0{,}2 \text{ m/sec.}$$

Similar calculations are made for component x, and the results are graphed.

The speeds need not be calculated for each point of a trajectory. It would be sufficient to apply, to the graph of first differences, an additional scale of speed values at the intervals calculated by the formula and corresponding to the values of the first differences.

7. Calculate accelerations. Acceleration (W)--that is, the rate of change of movement speed--may be interpreted as the speed of change in speed. Therefore everything said about speeds may be applied to acceleration, in which case we introduce the concept of second differences (Δ'') on analogy with the concept of first differences.

The first differences are the raw data used to calculate the second differences. The second differences are also calculated for every fourth point, though on the basis of the first differences and not the photographic measuring template. The obtained values are entered into the table.

Second differences are converted to acceleration values (W) using the following formula:

$$W_y = \frac{\Delta''y \ \gamma^2}{\beta^2 \times 1000} \text{ m/sec}^2.$$

A graph of the second differences (Figure 12B) is set up similarly as the graph of first differences, and an additional scale for the acceleration values calculated with the formula is applied on it (in m/sec^2).

This ends the kinematic description of the movement.

8. Calculate the dynamic characteristics--the muscle power required to surmount inertia and gravity.

Inertia (F_1) is equal to the mass of the segment (m), which is itself equal to the weight of the segment (gm) divided by gravitational acceleration (981 cm/sec^2). Inertia opposes both components of movement--x and y (forward and upward).

Muscle force (F) is expressed in kilograms. In the case of surmounting gravity,

$$F_p = p \times W_y,$$

where p--segment weight, kg; W_y--acceleration achieved during movement in relation to component y. This formula can be used to calculate forces corresponding to accelerations. Muscle force to surmount inertia (F_1) must be applied to both movement components--x and y. It also is expressed in kilograms.

$$F_1 = F_{1x} + F_{1y}.$$

In this case

$$F_x = mW_x \qquad F_y = mW_y,$$

where m--mass of the segment and rod; W_x and W_y--acceleration achieved during movement in relation to components x and y.

Thus the total force in relation to component y is equal to the sum of forces $F_p + F_1$, while only F_1 is applicable to component x.

We limit the description of muscle force only to movement component y because the kinematic characteristics of speed and acceleration are also analyzed only in relation to component y. The absolute values of the variables indicated above are obtained using known formulas. For speed for example, at each point we have $V = \sqrt{V_x^2 + V_y^2}$; for acceleration we have $W = \sqrt{W_x^2 + W_y^2}$.

9. The dynamic characteristic of movement is expressed by the muscle forces applied to the segment's center of gravity (in our example, to the center of gravity of the hand and rod). This indicator may be calculated on the basis of cyclographic data if the movement is opposed only by gravity and inertia (as in the case of lifting the rod).

Gravity is equal to the weight of the segment, and it is directed vertically downward. Consequently the muscle force required to surmount it must be applied upward in the direction of movement component y.

The technique described above for planar cyclophotography is intended for recording individual movements, or their phases, out of a series of repeating movements (otherwise the movements would superimpose over one another). If a successive series of movements must be analyzed, they would have to be photographed on moving film with a motion picture camera (naturally, this method can also be used to record individual movements or their phases). With motion picture photography, the number of frames taken per second must be known. The photographic measuring template is obtained by plotting successive points of the trajectory of movement on graph paper, projecting the film frame by frame onto the exact same place on the graph paper. This work must be done with special care so that subsequent calculations would come out correctly.

The advantage of motion picture photography is that in addition to permitting microanalysis of movements, a possibility is created for observing the progress of a movement in slow motion (using a high frame frequency), which is especially important to studying work procedures.

Using Motion Picture Photography to Study Movements

Motion picture photography is used in labor research to determine the time of individual procedures and work movements and to evaluate the efficiency of work movements, procedures and postures. The duration of individual procedures is determined from the number of frames on the movie film. If the work procedure is represented on 240 frames and the shooting speed is 24 frames per second, the duration of the procedure can be determined by calculation:

$$\text{Procedure duration} = \frac{\text{Number of frames for procedure}}{\text{Filming Speed}} = \frac{240}{24} = 10 \text{ sec.}$$

To evaluate the efficiency of work procedures and postures we lay a sheet of graph paper over the screen of an editing table, and the starting positions of both hands are marked on the paper. Then the film is advanced two or three frames, the new position of the hands is marked, and so on. The direction of movements and pauses in them are indicated concurrently. After the procedure is recorded in this way, the points representing movement of the hands are joined together: a broken line for the left hand and a continuous line for the right. Thus we obtain a cyclogram of the movements. Following this we use a curvimeter to measure the relative length of the movement paths. Figure 13 shows a cyclogram of two spinners, one less experienced (Figure 13A) and one more experienced (Figure 13B). A curvimeter would show that the length of the movement path of the less experienced spinner mending a broken thread is 130 percent of the path length of the more experienced spinner. Correspondingly the mending time is 13.1 percent longer for the less experienced than the more experienced spinner.

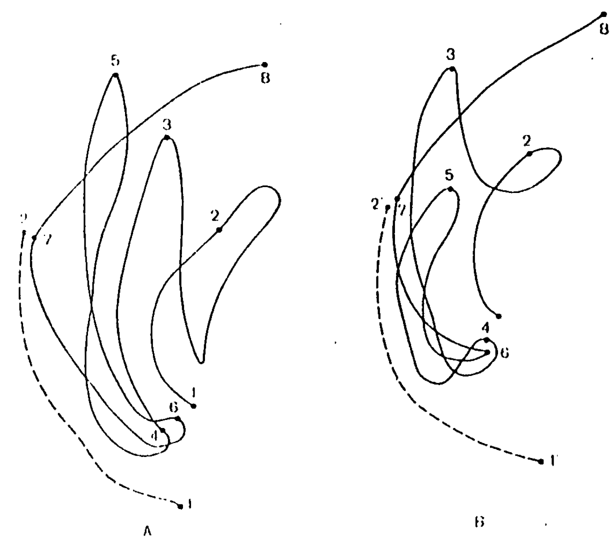


Figure 13. Cyclogram of the Hand Movements of a Less Experienced (A) and More Experienced (B) Spinner Mending a Broken Thread: Continuous line--movement of the right hand; broken line--left hand

In this way, we can also easily determine the effectiveness of teaching the best work procedures. Thus after being taught efficient procedures, the path length of the hand movements of a furrier decreased from 6 to 4.5 meters.

Because movie film can be viewed more than once, we can study and make work procedures and hand movements more efficient; by viewing a motion picture film, we can reveal and pin down unnecessary, extra procedures and movements, and thus get rid of them. S. Zhunda, the author of this modification of the method, believes that by using an intermittently switched-on movie camera we can also apply the "instantaneous observation" method.

Measurement of Forces

Measurement of the forces exerted by an operator while he is servicing equipment is often a necessity in ergonomic research. However, the methods of taking these measurements are still unsophisticated. The importance and need of such research stem both from the fact that physiological research has indicated a direct dependence between the amount of muscle force applied during work and functional changes in the body, and the fact that a measure of the forces required for control of equipment may serve as a basis for developing recommendations on their limitation. Of interest in this connection is a method for recording forces applied to production equipment developed by M. M. Speranskiy (1972). It entails recording the amount of force applied (by the palm and fingers) during the use of a control lever using several flat miniature sensors secured to the palm side of a special glove (Figure 14). In this case the object to which the force is applied may vary--the handle of a hand tool, a control, an article being worked, an article of athletic gear and so on. The sensitive element of the sensor consists of conductive rubber possessing the property of being able to decrease its resistance when compressed in volume. In this connection the sensor is designed in such a way that the tensometric element would be compressed by a force perpendicular to the surface of the sensor. Changes in the resistance of sensors joined together into bridge circuits elicit voltage changes in the latter which are amplified by a direct current multichannel transistorized amplifier and recorded by a high-speed multichannel recorder. The sensor's design protects the recording system from artifacts that may arise due to movement of the hand and fingers. Within a certain range, the voltage (current) at the amplifier output grows in proportion to the force applied to the sensor. The resulting dynamograms are subjected to quantitative evaluation (in kg) on the basis of the calibration of the recording system.

This method can also be used successfully to evaluate the quality of seats. The quality of a seat depends on how uniformly pressure is distributed over the surface of the gluteus muscles. The nature of this pressure's distribution can be determined by distributing a large quantity of Speranskiy sensometric sensors over the surface of the seat and subsequently recording the pressure applied to different parts of the seat surface. The shape of the seat surface may be altered in correspondence with this pressure distribution, so as to achieve more-uniform distribution of loads on different surfaces of the gluteus muscles.

In a number of cases conventional dynamometers can be used to determine the forces exerted on used equipment. Thus for example, dynamometers are used successfully to evaluate forces applied when manipulating control sticks, steering wheels and so on; a particular example is the spring dynamometer used by the State Motor Vehicle

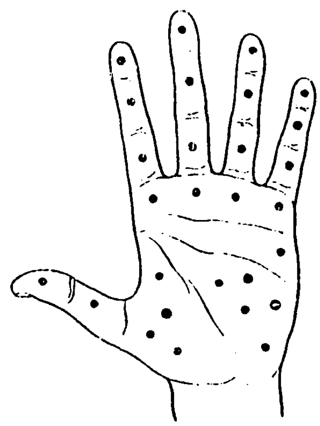


Figure 14. Distribution of Tensometric Sensors Over the Surface of the Palm in M. M. Speranskiy's Method

Inspection to measure the force necessary to turn the steering wheel of a motor vehicle. This spring dynamometer is secured to the rim of the steering wheel. The force generated when turning the wheel is shown on a scale marked on bushings on which the dynamometer rests. Presence of two springs permits measurement of forces in ranges from 0.9 to 2 and from 2 to 10 kg.

Yu. G. Shirokov and V. P. Silant'yev proposed a method for quantitative evaluation of loads experienced by the hands. They designed a tensometric device that could differentiate the points of application of forces, in kg, reveal the loads with regard to the time of their action upon the muscle (indicator I, equal to the product of force P, kg and the time of its action t: $I = P \times t$ kg·sec) and evaluate the loads simultaneously experienced by many muscle groups of the arm.

By determining indicator I, kg·sec, we can describe the loads both on individual muscles of the hand and on entire muscle groups during work.

Figure 15A shows a diagram of the device used to conduct myotensometric research.

This method is based on measuring forces by means of tensometric converters--tensometers.

The device consists of a sensitive element--a glove (Figure 15B), to which thin metallic plates with glued-on tensometric resistors are secured within the zone of the muscles to be analyzed.

The leads of all of the tensometers are located on the back side of the glove, and they are connected by a long cable and plug connection to a bridge block, in which each tensometer is the leg of a corresponding bridge.

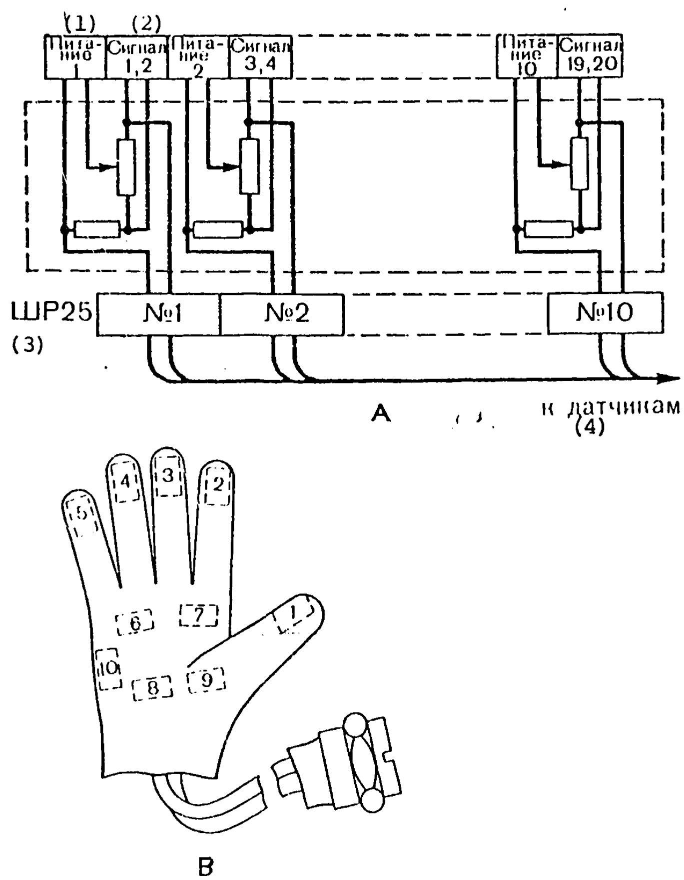


Figure 15. Tensometric Sensor Connection Circuit: A--bridge block; B--tensometric glove; *1-10*--tensometric sensors

Key:
1. Power
2. Signal
3. ShR25
4. To sensors

Type PKB sensors without hysteresis and with resistance *R* depending insignificantly on temperature *t*, °C, may be used.

The essence of the method is as follows: As a result of forces experienced by different regions of the hand in the course of physical work, electric bridge unbalance signals are fed separately to the inputs of a direct current multichannel amplifier--a UPT, from the output of which the signals are fed to a recording block (a cathode-ray oscillograph or recorder).

Before recording begins, a special device is used to "calibrate" the sensometers which are subjected to a previously known force P_{cal}, kg.

The analysis of the myotensogram may be both qualitative and quantitative.

Tabular Method for Evaluating Workplace Organization

Among the methods for evaluating the organization of workplaces at which production equipment is serviced, tabular analysis of the correctness with which handles, buttons and other fixtures are located on a control console has great significance.

The chief problem usually solved by the method of tabular analysis is that of clarifying when and in what sequence the operator manipulates different controls. In other words it is used to determine the number and sequence of the operator's contacts with different controls. In this method, controls are coded by means of certain symbols, and these symbols are entered across the top and down the left column of a table (Table 4). Then the work of an operator is observed, in the course of which all of the operator's contacts with the controls are recorded in succession. After the observations are all made, the total number of the operator's contacts with different controls and the sequence of these contacts are determined at the bottom of the table.

Table 4. Table of Contacts

	Органы управления (1)											
	A	B	C	D	E	F	G	H	I	J	K	L
A	—	3	4	2	10	9	8	—	7	—	—	3
B	3	—	1	2	—	5	—	7	—	14	10	—
C	4	1	—	4	20	12	—	15	3	4	—	15
D	2	2	4	—	7	16	—	10	—	5	9	—
E	10		20	7	—	7	6	17	21	10	12	—
F	9	5	12	16	7	—	8	—	13	—	—	20
G	8	—	—	—	6	8	—	3	8	20	9	—
H	—	7	15	10	17	—	3	—	—	18	4	—
I	7	—	3		21	13	8	—	—	5	—	—
J	—	14	4	5	10	—	20	18	5	—	—	—
K	—	10	—	9	12	—	9	4	—	—	—	—
L	3	—	15	—	—	20	—	—	—	—	—	—
(2) Число связей	46	42	78	55	110	90	62	74	57	76	44	38

Key:
1. Controls
2. Number of contacts

We can see from the example of tabular analysis shown in Table 4 that the operator made the largest number of contacts with the control with the code letter E. In terms of their sequence, they are usually combined into successive control manipulations--EI, EC and so on. Hence we can conclude that control E must be located in the most optimum zone, and the controls which the operator manipulates most frequently following use of control E should be located near it.

Table 5. Relative Load in Response to the Existing and an Efficient Keyboard Arrangement (Number of Times Struck by Each Finger)

Keyboard Arrangement	Fingers of Left Hand				Fingers of Right Hand			
	5	4	3	2	2	3	4	5
Existing	803	658	1492	1535	1490	640	996	296
Efficient	855	900	975	1028	1097	1096	991	968

Table 5 shows a simple example of using the tabular analysis method to determine the efficiency with which keys are distributed on a common typewriter keyboard. As we can see from the table, the load experienced by different fingers (assuming work with four fingers of each hand) using the existing keyboard arrangement varied from 296 (the little finger of the right hand) to the 1,535 (fourth finger of the left hand) and 1,490 symbols (index finger of the right hand). A very large difference in the load experienced by each hand by different fingers is evident. Therefore the keys were redistributed in a new, efficient order; as can be seen from Table 5, the load on the hands and fingers became more uniform. Other applications of the tabular analysis method will be discussed subsequently.

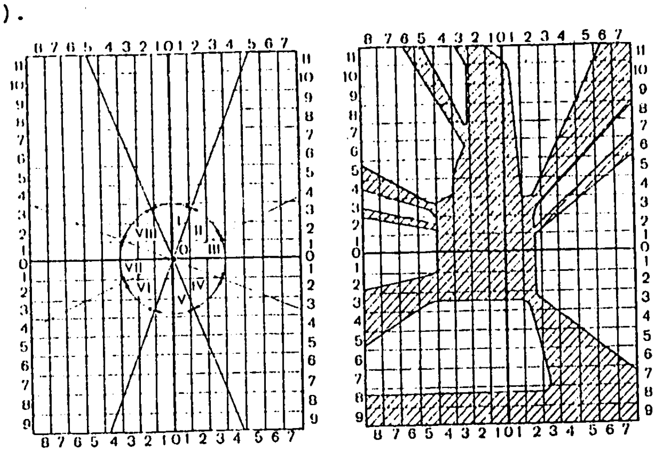
Determination of Field of View

One of the most important problems in ergonomic evaluation of equipment is that of determining what the field of view is. This is especially important to evaluating the visibility qualities of tractors, agricultural machines and other self-propelled machines. A method used to determine the visibility qualities of these machines must account for the way the driver perceives visual information (the manner in which he switches his attention and fixes his gaze on particular objects of observation), his physiological characteristics (quantitative data on movement of the driver's eyes, head and body during perception of visual information) and technological requirements (the required visibility of observed objects during performance of production operations). It must also consider the convenience and safety of the driver's entry into and exit from the cab (biomechanical and temporal parameters) and the comfortableness of the driver's location in the cab. This method basically entails using panoramic and motion picture photography to determine the quantitative and qualitative parameters of visibility. By comparing the characteristics of a driver's perception of visual information and data describing the visibility qualities of machines and the technological requirements of visibility, we can determine the optimum cab design and location on the machine.

To evaluate the visibility qualities of tractors, we determine the angles of view from the cab in the vertical and horizontal planes, the fields and areas of view in angular and linear units, "dead zones" that cannot be seen from the cab, and the visibility of observed objects from the cab.

Visibility parameters are determined for the cabs of tractors and agricultural machines using a special level platform to which a coordinate grid is applied (the sides of the squares are 1 meter, the length of the platform is 20 meters, and its width is 15 meters) (Figure 16A,B). This method entails the use of a panoramic camera, a special tripod designed by the State Scientific Research Institute of

Motor Vehicle Transportation, a 50 kg weight and a measuring instrument. To photograph the pattern of visibility, the tractor or the given piece of machinery is priced on the platform in such a way that the platform's axes would coincide with the axes of the center of the camera's lens (point 0). The tripod and camera are set up on the seat, with regard to its sag, in such a way that the camera lens would be at a point corresponding to the position of the eyes of a driver with average anthropological characteristics: $a = 77$-78 cm, $b = 19$-20 cm (Figure 17). The 360° panorama is photographed from the cab with the camera in eight positions (I-VIII, see Figure 16A). The resulting 360° panoramic photographs are used to compile a table and draw a diagram (see Figure 16B) characterizing the quantitative parameters of cab visibility. Figure 18 demonstrates the significance of visibility (the contour of the invisible zone) to selection of tractor cab design. The fourth variant is preferable in terms of visibility (59).



A B

Figure 16. Coordinate Grid on a Marked Cab Visibility Platform (A) and Diagram of Visibility From the Workplace (B): Cross-hatched areas--invisible zone

A cab's visibility may also be evaluated by means of special coefficients. Thus I. Trepenenkov (1969) proposed a total visibility coefficient and supplementary partial indicators. The total visibility coefficient is defined by the expression:

$$K_t = \frac{F_o}{F_i - F_o},$$

where F_o--area contained within tractor outline in plan view; F_i--area of invisible zone.

Good visibility is within $K_t = 0.25$-0.35.

Mention should be made of the light-shadow method for determining visibility. The determination is made with this method in darkness. A lamp is supported by the appropriate devices at the point where the driver's eyes would be. When the lamp is

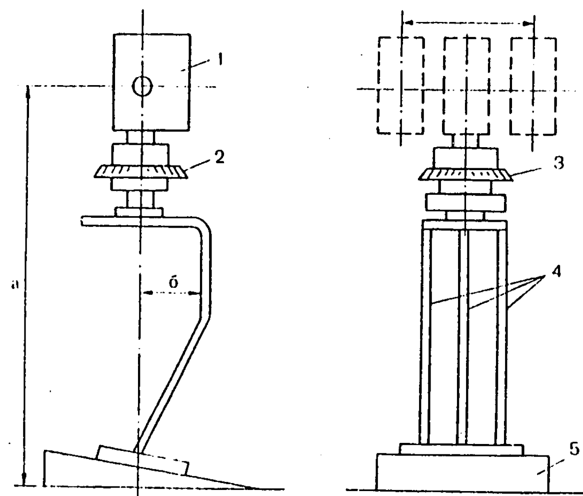


Figure 17. Line Diagram of a Device for Panoramic Photography of Cab Visibility: 1--camera; 2--graduated circle ; 3--guide strip; 4--tripod legs; 5--tripod base

turned on, a black silhouette of the machine appears over the surface of the platform. Shadows on the platform indicate presence of various opaque parts of the tractor's structure within the field of view. The outlines of the illuminated zones are transferred to a graph, and the latter is used to determine the visibility parameters.

Evaluation of Operator's Work Posture

Evaluation of the operator's work posture occupies a great place in ergonomic evaluation of the mutual relationships between an operator and his equipment. It is a summary evaluation of these mutual relationships. The assessment of work posture is the sum of the general characteristic describing the position of the operator as "standing," "standing-sitting" or "sitting" or some other general characteristic, and the characteristics describing the positions of individual parts of the body and joints, and the angles between them. If the work of an operator requires different work postures, we would have to know the distribution of the different work postures in time in order to reveal the main ones.

There are several methods for evaluating work postures. Very often researchers limit themselves to verbal description or photography. The angles of different articulations may then be determined from the photographs. There are also instrumental methods for evaluating work postures and their dynamics. A. G. Sukharev (1961) proposed the photogoniometric method for evaluation of the work postures of students working at drafting tables. In this method a student working in close-fitting clothes bearing identification points is photographed in profile. The identification points correspond to the top of the cervical curvature, the top of the thoracic curvature, the top of the lumbar curvature, the top of the head, and the humeral, radial and styloid points on the arm. Photographs are taken 2 minutes apart. Thus a series of 22

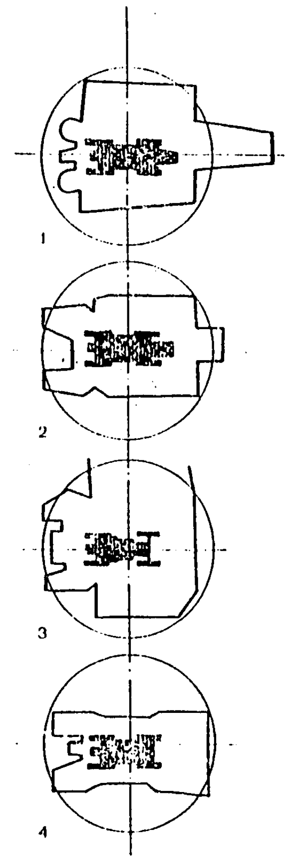


Figure 18. Field of View From Different Tractors: The fourth variant is preferable

photographs is obtained in one study lasting the time of a class period--45 minutes. The identification points on each of the photographs are joined together by straight lines, and the angle formed by each line and the horizontal line passing through the given identification point is determined. These angles represent the tilt of individual parts of the bodies of the students during work. In this case the smaller the angle, the greater is the tilt of the spine. By averaging the angles determined from 400-500 different subjects, to a certain extent we can exclude the possible influence of "chance" postures typical of the sitting habits of individual subjects, and we can say that we have arrived at the typical work posture depending on the height of the table and the particular features of the work. The periodicity of photogoniometry also allows us to trace the dynamics of changes in posture during a class period.

The nature of work postures and their dynamics during work may also be determined by motion picture photography using special flat dummies on which swivel joints represent the joints of the body.

In order to permit continuous registration of the work posture in industrial conditions, V. P. Silant'yev designed and manufactured a device recording the tilt of the torso during performance of work operations, the number of times it is tilted and the time the body maintains a work posture.

This small device converts angular displacements into electric signals proportional to tilt, in degrees, and subsequently records these values on a recorder chart. The converter consists of two halves of a fiber glass disk glued together and containing grooves filled with mercury. Electric contacts connected to a voltage divider are built into the disk. When the torso tilts forward or backward the column of mercury closes the appropriate contact, and an electric signal passes to the recorder input.

This device was tested at two tire plants on different assembly equipment, and experimental results describing the effectiveness of the device's use for ergonomic research were obtained. Work postures have been subjected to mathematical analysis in a number of projects.

Testing Units

In many cases it is found necessary to evaluate an ergonomic system in its entirety or its parts. In such cases we use testing units and mock-ups or models of the system. Thus Kozlov (36) used a special ergonomic testing unit to establish, by means of special ergonomic (see above) and physiological methods, the optimum parameters for the location of tractor levers and pedals in relation to the seat and arm rests. He also revealed that visibility plays a significant role in determining the nature of the work posture. Because of certain defects in visibility that he revealed, tractor operators were compelled to work in an asymmetrical posture, tilted to the right (Figure 19).

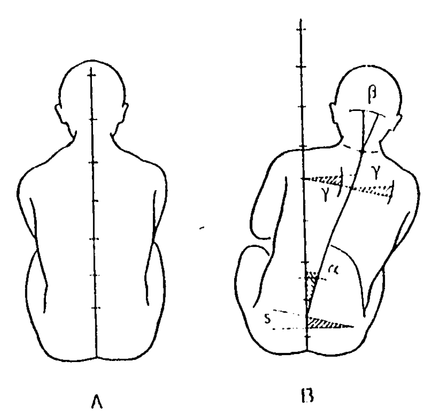


Figure 19. Efficient (A) and Forced (B) Work Posture of a Tractor Driver

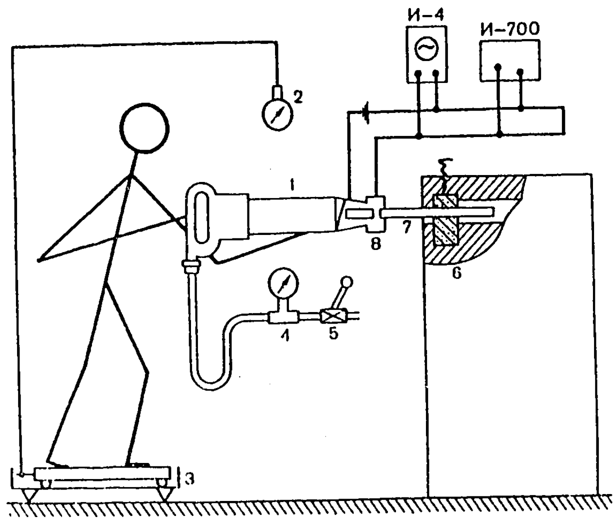


Figure 20. Location of a Person and Equipment Undergoing Testing to Determine Basic Permissible Conditions: 1--pneumatic drill; 2--pressure gage recording applied pressure; 3--measuring platform; 4--pressure gage recording compressed air pressure; 5--compressed air pressure regulator; 6--friction absorber; 7--tool simulator; 8--contact ring

The biomechanical conditions of maintaining an asymmetrical posture can be described by the amount the body's center of gravity is displaced to the right and by the amount muscle static tension is increased due to inadequate visibility. A posture would be undesirable from the biomechanical standpoint if the spine is tilted in relation to the horizontal plane (α), if the shoulder girdle and pelvis are tilted laterally in relation to horizontal, and if compensatory scoliosis of the spine arises in the cervical and lumbar divisions.

N. P. Benevolenskaya (1972) studied pulsed-action mining equipment (riveting, chopping and pneumatic hammers) with testing units at the USSR Academy of Sciences Institute of Mining (Figure 20).

A mock-up of a grinder was developed at the ergonomics laboratory of the USSR Academy of Medical Sciences Institute of Labor Hygiene and Occupational Diseases (38). This mock-up simulates the work of a grinder with the purpose of establishing the optimum location of the grinder's controls, and the forces exerted by the operator (Figure 21).

Method of Evaluating Informational Interaction.*

The methods of ergonomic evaluation of informational interaction between and operator and a machine are an important but little-studied area. An operator's work involves

*Described in "Praktikum po fiziologii truda" [Handbook of Labor Physiology], edited by K. S. Tochilov, LGU, 1970.

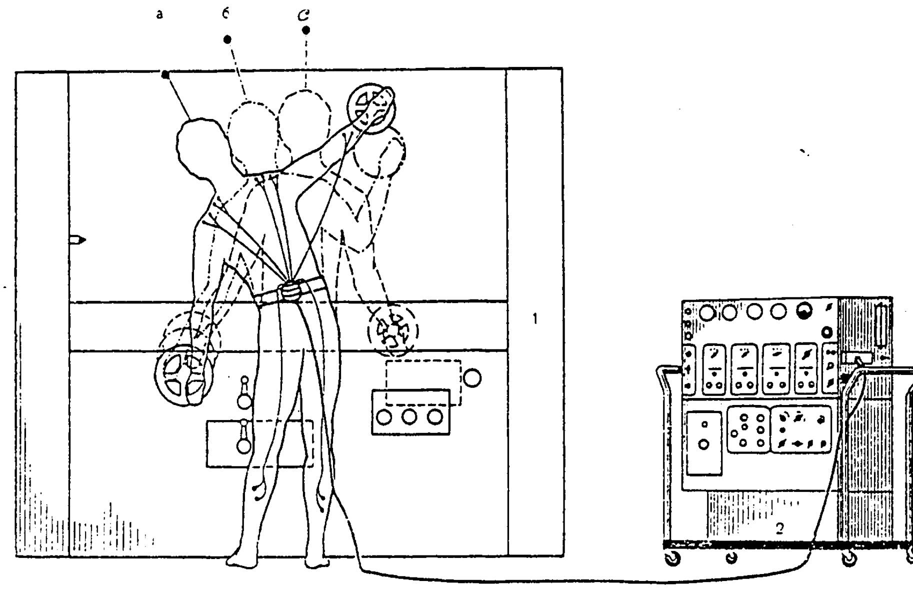


Figure 21. A Study Performed to Optimize a Machine Tool Operator's Work Posture by Changing Locations of the Principal Controls on a Mock-Up: 1--mock-up: *a*--existing work posture, *b*--improved work posture, *c*--optimum work posture; 2--electromyograph

recognition of displayed signals; therefore we must know the rate at which his sense organs, and the visual analyzer in particular, perceive and process information.

The recorded time of a choice reaction to a certain visual stimulus consists of the time required to receive the information in the visual system, the time to form a motor reaction in response to the obtained information and the time required for the signal to travel efferent pathways to acting organs--that is, the measurement of the choice reaction time does not differentiate between information processing time in the visual and motor areas. The temporal characteristics of the work of the visual system itself may be studied by presenting a visual image for a certain length of time and determining the quantity of information obtained by the observer during this time. This procedure is what is used in psychophysiology to measure the rate of visual perception.

A tachistoscopic method can be used to measure the rate of visual perception. Tachistoscopy is short-term presentation of images. A tachistoscope is an instrument displaying an image for any desired length of time.

Because man's visual system includes a working memory that retains an image of an object for more than 250 msec following its disappearance from the field of view, when images are presented by means of conventional tachistocopes without an attendant

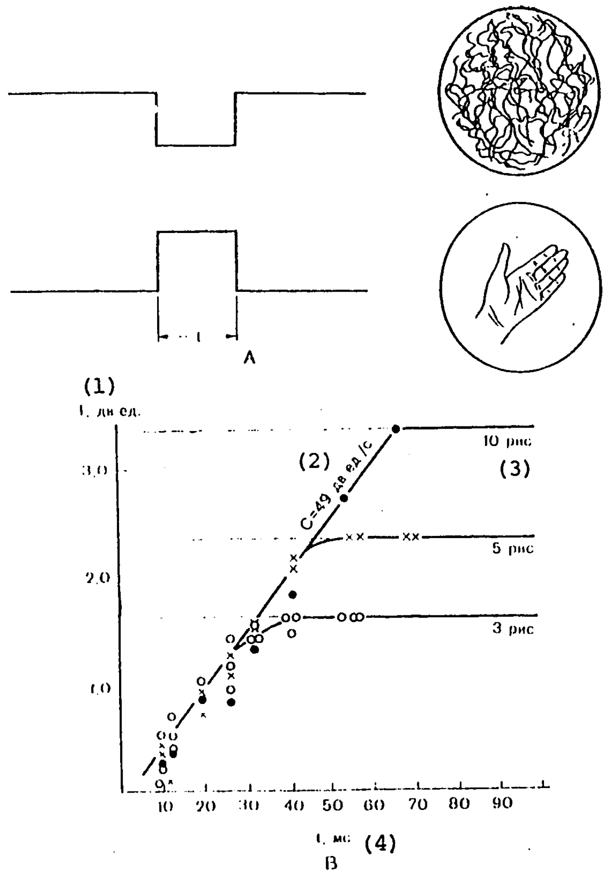


Figure 22. Diagram Showing Presentation of Test and "Attendant" Images (A): *t*--test image exposure time. See text for explanation. Dependence of Average Quantity of Information (*I*) Received by the Observer on Image Presentation Time (*t*) (B): Sets of three, five and ten images had to be identified (V. D. Glezer, A. A. Nevskaya, 1964)

Key:
1. Binary units
2. Binary units/sec
3. Figures
4. Msec

image, the time allowed for their identification is not really limited. If following presentation of a given image, called a "test" image, the subject were to be shown another called an "attendant" image, the first ("test") image could be "erased" from the working memory, thus switching the visual system to solution of a new task. The exposure time of this image would reflect the time required by the visual system to process information about it.

S. S. Siklan was the first to propose a method for determining the time required by the visual system to identify an image. He used television apparatus to present images. This method was later improved. Then A. A. Nevskaya designed an optical device permitting smooth change in exposure time from 3 to 700 msec, something the television apparatus could not do. Observation is monocular in this case. The Leningrad University laboratory of labor physiology developed a similar binocular observation device permitting presentation of an image for from 6 to 200 msec. The image is projected onto a screen by two general purpose projectors.

A slide is secured in a convergent beam of light directly behind the last lens of the condenser, near the focal plane of the projector's lens. This slide is projected onto the screen by the projector lens. At the same point the light beam is interrupted by a curtain secured to a relay. When a pulse of one duration or another is fed to the relay the "test" image comes on and the "attendant" image goes off; after this time expires the "attendant" image is flashed back on. The exposure time is set by means of an ELS-1 electrostimulator. The device's principle of operation is shown in Figure 22A. While the "test" image is being presented the "attendant" image is shut off, and vice versa. An attachment permitting measurement of the latent period (LP) of the combined sensory-speech reaction has been made.

Different sets of images can be presented to an observer for a particular amount of time by means of this method. The object of the observer is to determine and name the presented image. Following this, a formula is used to determine the average quantity of information obtained by the observer in a given presentation time. When the presentation time is long, no mistakes are made in identification and the quantity of received information corresponds to the quantity given. If time is short, the observer is unable to receive all of the necessary information, and he gives wrong answers.

Here is an example of calculating the average quantity of information received by an observer in an experiment with a test object presentation time of 56 msec. Four lines of different lengths were presented: 1, 2, 3 and 4 angular degrees. All images (x) were equiprobable. A table describing the distribution of responses in relation to the given presentation time was compiled on the basis of the obtained responses (y) (see below).

The average quantity of information received by the observer during this presentation time can be calculated using Shannon's formula:

$$I = H_x + H_y - H_{x,y},$$

x	(1) Ответы (y)					(3) Всего
	1	2	3	4	«не знаю» (2)	
1	10	0	0	0	2	12
2	0	11	0	0	1	12
3	0	0	11	1	0	12
4	0	0	0	12	0	12
Всего... (3)	10	11	11	13	3	48

Key:
1. Responses
2. "Don't know"
3. Total

where $H_x = -\Sigma P_x \log_2 P_x$ --entropy of the probability distribution of the presented images*; $H_y = -\Sigma P_y \log_2 P_y$ --entropy of the probability distribution of the subject's responses; $H_{x,y} = -\Sigma P_{x,y} \log_2 P_{x,y}$ --entropy of the joint probability distribution of arisal of image x and response y. Because all four images are equiprobable in the experiment,

$$H_x = \log_2 4 = 2 \text{ binary units (bits)}$$

$$H_y = -\left(\frac{10}{48}\log_2\frac{11}{48} + \cdots + \frac{3}{48}\log_2\frac{3}{48}\right) = 2{,}20 \text{ bits}$$

$$H_{x,y} = -\Sigma p_{x,y} \log_2 P_{x,y} =$$

$$= -\left(\frac{10}{48}\log_2\frac{10}{48} + \frac{2}{48}\log_2\frac{2}{48} + \cdots + \frac{12}{48}\log_2\frac{12}{48}\right) = 2{,}37 \text{ bits}$$

Thus the average quantity of information in this case would be 2+2.20−2.37 = 1.83 bits per presentation. In other words in 5.6 msec the subject receives only 1.83 bits of information out of the signal's total information of 2 bits.

The calculations are similar with other presentation times.

The obtained data are used to plot the dependence of the average quantity of information received by the subject on the image presentation time. Figure 22B shows the results of experiments with different sets of images. The quantity of information the human visual system is capable of processing and transmitting in a unit of time

*The $P \log P$ values needed for the entropy calculations may be taken from the tables in the book "Veroyatnost' i informatsiya" [Probability and Information] by A. M. Yaglom and A. I. Yaglom (Moscow, Fizmatgiz, 1960).

is its capacity. Channel capacity (C) can be determined by the formula:

$$C = \frac{I}{t},$$

where I--average quantity of information, bits; t--time, in seconds, during which this information is received. For example we can see from Figure 21B that 2 bits were obtained in 41 msec; hence $C = 49$ bits/sec; or if 2.7 bits are received in 55 msec, $C = 49$ bits/sec. The slope of the curve reflects the capacity of the visual system in binary units per second.

The image identification time and the capacity of the visual system can vary within certain limits depending on the dimensions of the images presented, differences in the brightness of the visual field, the thickness of lines on the images and so on. Therefore depending on the factor under analysis, care must be taken to keep all experimental conditions as constant as possible.

III. HYGIENIC CRITERIA OF ERGONOMICS

Physiological Basis of the Biological Action of Factors in the Production Environment

One of the most important objectives of ergonomics is to come up with requirements on production equipment design and workplace organization which, when satisfied, would ensure optimum hygienic working conditions in industry. These requirements are founded on physiological data describing the particular biological effects of hygienic factors upon the human body, and the hygienic standards based on these data. Among the problems associated with the biological action of hygienic factors, the most important include the laws of the body's reactions, reflecting the informativeness of the operating factors, the laws governing the strength and time of their influence, the particular dynamics of the body's reactions to the influence of certain hygienic factors and the laws of the body's adaptation to operating factors on the basis of information received by functional integration systems. A knowledge of these aspects of biological action is what would permit us to confidently approach evaluation of production equipment design and workplace organization in industry. Let us successively examine these most general laws of the body's reactions to the influence of factors in the production environment.

Biological Action of Hygienic Factors Depending On Their Informativeness

The mutual relationships between living organisms and the environment have great significance to the vital activities of such self-regulating systems. These mutual relationships are structured upon perception of effects coming from the environment, their transformation and coding into nerve impulses, transmission of the latter through diverse nerve pathways and formation of responding reactions. It is believed in this case that environmental effects introduce certain information into the body, the content of which determines the response.

There are presently believed to be three possible means of information transmission: transfer of information together with an information carrier, the matrix form of information transmission and transmission of information via special communication channels.

All of these information transmission methods are said to occur in living organisms when they interact with environmental factors. We will see below how these methods of information transmission manifest themselves in the organism in the course of formation of responses to the effects of hygienic factors.

As Shalyutin pointed out (68), if we are to determine the quantity of information contained in a given effect, we must know the quantity of qualities characterizing this effect, for example the energy it brings with it, its dose, concentration, repetition rate, duration etc. These qualities are what determine the modality of the effect. Next we need to know the number of possible gradations or steps in each quality. Shannon's formula, which accounts for these data and has its origins in information theory, can be used to calculate the amount of information contained in each effect. The formula has the form $I = n\log_2 m$, where n is the number of qualities possessed by an effect, m is the number of gradients of each of its qualities, and log is the base 2 natural logarithm.

Effects bearing the same information may also differ in relation to their code--that is, the relationship between n and m. Thus at $n = 3$, $m = 2$ information would equal 3: $I = 3\log_2 2 = 3$. However, at $n = 1$ and $m = 8$ information would also be equal to 3 units of information (bits): $I = 1\log_2 8 = 3$.

Using these data and knowing the particular features of a given effect, we can calculate information contained in a given hygienic factor. Thus Shannon's formula allows us to calculate the quantitative value of information introduced by a particular effect into the body.

Given the enormous significance of the possibilities for quantitatively accounting for information using Shannon's formula, it should nevertheless be pointed out that many features of hygienic factors are ignored when their biological action is evaluated in this way. Thus for example, when we consider the energy (intensity, dose, concentration) of a given effect, we ignore its possible signaling significance. If the appropriate conditional associations are developed, a signal having a negligible energy level or negligible dose and concentration may elicit an unusually violent response. In precisely the same way, stress reactions elicited by particular effects do not adhere to specific energy and intensity (dose, concentration) relationships.

On the other hand purely mathematical representation of information cannot account for possible changes in formation of responses due to changes in the initial functional state of the body, for example changes in attention level, presence of dominants, tiring and so on. All of this indicates that a purely mathematical approach to studying the biological action of hygienic factors without accounting for physiological data cannot ensure a correct understanding of the relationship of a given effect to a particular response. In this connection we will attempt to demonstrate the dominant role played by the physiological approach to understanding the informativeness of hygienic factors.

Much research is presently being carried out on differences in the informativeness of the continuous and intermittent action of many industrial and environmental factors on the body. An example would be the stable and discontinuous (intermittent) action of production noise.

Although we know from experience that the intermittent, flickering action of noise, light, heat and so on is subjectively perceived by man as a stronger and more unpleasant influence, scientific research on this problem has not yet led researchers to any firmly established explanations for this difference. But at the same time physiological science possesses a number of established facts which allow us to approach, from a scientific standpoint, the question as to why intermittent action is more informative.

We should first of all point out the fact that as long ago as in 1843, the well known physiologist E. De Bois-Reymond established in research on the action of direct current on a nerve that the latter is stimulated not so much by the intensity or the power flux density of direct current as by the rate of their change. In other words 136 years ago Du Bois-Reymond formulated the law of infomativeness of the action of direct current not as $I = kF \cdot t$--that is, not as a proportion between the informativeness of direct current of intensity (F) and the time of its action (t), but rather in the form $I = kdF/dt$--that is, as a proportion between the informativeness of the action of direct current multiplied by the intensity of the operating current, and the time of its action. We can see from a mathematical standpoint that in the second case an effect may achieve greater informativeness not only by increasing the intensity of action but also by varying the rate of its change in time. Thus the data of Du Bois-Reymond and mathematicians suggest to us a direction of research in which reliable ideas on the greater informativeness of intermittently acting factors may be obtained. Du Bois-Reymond's law, however, says nothing about the role played by the frequency with which certain effects are interrupted in relation to their informativeness. Nevertheless such data do exist in physiology, among which N. Ye. Vvedenskiy's data on parabiosis and on the optimum and pessimum levels of stimulation should receive priority attention. Effects which are interrupted at a frequency lying within optimum limits have the greatest force of action, and therefore the greatest informativeness to the organism. This premise is fully valid in relation to effects such as constant current and the like--that is, nonoscillating effects. Another criterion is used by physiologists wishing to evaluate differences in the informativeness of oscillatory effects such as, for example, sound and light, operating continuously and intermittently. This criterion is the critical flicker fusion frequency. We know that intermittent light ceases to be perceived as flickering light at a flicker frequency varying within 25-50 light flashes per second, depending on the individual features of the organism's state. This critical flicker fusion frequency is said to be an indicator of the lability of the visual analyzer. The critical fusion frequency for sound is 40-100 interruptions of sound per second, while according to some other data it is within 90-140 interruptions per second.

It becomes obvious from these data that differences in the informativeness of continuous and intermittent effects may be discovered by interrupting the factor under analysis within the limits of its critical flicker fusion frequency, since a stimulus with a higher frequency would be perceived as continuous--that is, as stable, with its informativeness equal to that of a continuous effect. Evidence that intermittent action is capable of increasing the informativeness of a factor under analysis may be found in experiments performed by S. I. Gorshkov and Ye. A. Guseva back in 1932. As had been hypothesized, when a nerve in a neuromuscular preparation with its circulation intact was stimulated by a frequency of 200 oscillations per second, the muscle reacted with minimum contraction. However, when this minimum stimulus was interrupted 20 times per second, during these breaks in stimulation the muscle reacted with a contraction having an intensity that was, judging from the myogram, 50-100 times greater than in response to the initial stimulus; consider this in light of the fact that following the interruptions, the frequency of the stimulatory pulses remained equal to 100 pulses per second--that is, also at the minimum level (Figure 23).

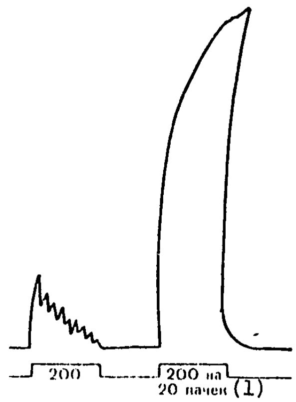


Figure 23. Results of Stimulating a Nerve in a Neuromuscular Preparation at a Frequency of 200 Pulses Per Second, and by 20 Pulse Trains Per Second With Five Stimuli in Each Train: Dramatic intensification of muscle contraction can be seen

Key:
1. 200 in 20 trains

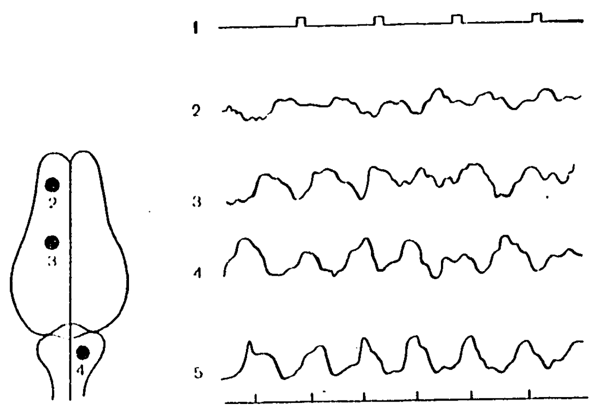


Figure 24. Irradiation of an Assimilated Rhythm in the Rabbit Brain (EEG Recorded in the 40th Minute Following the Start of Stimulation of the Right Sciatic Nerve): *1*--1 second time marks; *2-3*--EEG's of the anterofrontal and posterofrontal cortical regions; *4*--respiratory center potentials; *5*--pneumogram, stimulation marks

Physiological data provide a way for narrowing down the frequency of interruptions at which the biological action of intermittent stimulation is greater than that of continuous stimulation. Other features of the central nervous system's reaction must be considered here, particularly its ability to assimilate a rhythm.

Assimilation of the rhythm of external effects was first described as a phenomenon by A. A. Ukhtomskiy at the Third All-Union Congress of Physiologists in 1928 in his report "Rhythm Assimilation in Connection With the Teaching on Parabiosis." Ukhtomskiy demonstrated that the functional mobility of nerve centers, receptors, muscles and other excitable formations may be altered by rhythmical stimulation, and that rhythm assimilation has important coordinating significance to the activity of the central nervous system and the integral organism. Later on, Ukhtomskiy's students and colleagues showed that an activity rhythm may be imposed upon any organ by external rhythmical stimuli (Figure 24). Thus a rhythm of bioelectric activity may be imposed upon the cerebral cortex by rhythmical light and acoustic stimuli; this method is now being used extensively as a means for evaluating the functional state of the cerebral cortex. Rhythmical effects can be used to change cardiac and respiratory rhythm, blood pressure and motor activity in man. Everyone has experienced assimilation of the rhythm of march music, or has observed involuntary motor acts within himself during a concert.

Electroencephalographic research has shown that if a rhythmical light or sound stimulus is turned on at the time an EEG is being recorded, some of these stimulation frequencies that are close to the frequencies of the EEG are assimilated and can be revealed in the recording. As a rule those frequencies of light and sound stimuli which correspond to the level of the subject's functional state are assimilated best. At the same time, light and sound stimuli can be used to impose a stimulation rhythm upon the subject's central nervous system and thus shift his functional state in one direction or another. Slow δ- and Θ-rhythms (1.5-3 and 4-7 oscillations per second) are known to correspond to a decline in functional state of the central nervous system, the α-rhythm (8-13 oscillations per second) corresponds to a resting central nervous system, and the β-rhythm (14-35) and γ-rhythm (up to 90 oscillations per second) correspond to heightened activity of the central nervous system. Hence imposition of an external stimulus having a certain rhythm may promote establishment of a particular level of the organism's state. Consequently the significance of intermittent stimuli may depend on the rhythm with which they are interrupted, and on whether or not this rhythm coincides with a certain rhythm of bioelectric activity in the cerebral cortex, typical of the current state of the organism.

These physiological facts allow us to approach, with valid scientific grounds, organization of research on intermittent and continuous effects and analysis of the obtained results.

Thus the physiological effects demonstrate that the frequency of pulsations in external effects has informative significance, as a rhythm assimilation factor, basically within the limits of the critical flicker fusion frequency, and that the most pronounced biological action is observed at frequencies assimilated by the organism's excitable formations, and particularly when the external rhythms correspond to the rhythms of the bioelectric activity in the cerebral cortex.

While rhythm assimilation phenomena may be enormously significant to determining the informativeness of factors in the surrounding and work environment, work on this problem has only just begun. There are absolutely no scientific data in the literature on the particular ways rhythm is assimilated or on the particular features of the pulsating action of chemical, thermal, tactile and other effects. As was shown, however, these problems have a direct bearing on the informativeness of their biological action, particularly when we consider that these and other effects are frequent sources of information from the surrounding and work environment, owing to which they should become an object of special investigation.

It must be pointed out specifically in regard to the biological action of noise that the present information on noise has to do only with the biological action it exerts when adequately perceived by the hearing organ. However, as we can see from Figure 25, noise acts not only through the hearing organ but also, when it attains a certain intensity, through the entire body surface, as is shown in the upper part of the figure. According to experimental data published by S. I. Gorshkov and R. M. Nikol'skaya (1978), the threshold for perception of 2,000 Hz acoustic oscillations through the body surface when the organ of Corti is damaged is 120 db, while the threshold for 10,000 Hz is 110 db. In this case, as we can see from Table 6, perception of noise through the surface of the body, without the ear's participation, produces manifestations of its biological action upon the state of the organism which differ fundamentally from the changes caused in the state of the organism by perception of noise through the hearing organ.

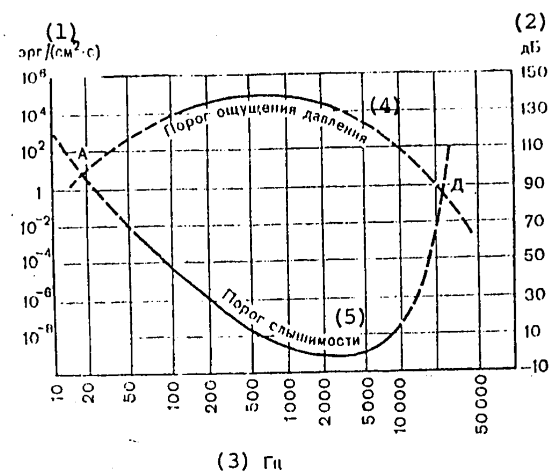


Figure 25. Sensitivity of the Human Ear to Different Frequencies of Airborne Oscillations ((Vegel'-Gil'demeyster) Curve, From A. A. Ukhtomskiy): See text for explanation.

Key:
1. ergs/($cm^2 \cdot sec$)
2. db
3. Hz
4. Pressure sensation threshold
5. Audibility threshold

While changes in the state of the nervous system occurring in response to suprathreshold, one-time, 1-hour adequate noise with a frequency of 2 or 10 kHz elicited a one-time lengthening of the latent time of the reaction to painful electrocutaneous or elevator* stimulation only on the day of

*"Elevator" stimulation is defined as stimulation of the vestibular apparatus by a sudden fall.

Table 6. Comparative Data on the Particular Features of the Biological Action of Acoustic Stimuli Perceived Adequately (by the Ear) and Inadequately (by Other Than the Ear)

Physiological Indicator	Means of Perception of Acoustic Effects	
	Adequate	Inadequate
Latent time of reaction to electrocutaneous stimulation	Monophasal lengthening of latent time on the day of exposure	Biphasal lengthening of latent time: 1st phase--on the day of exposure, 2d phase--on the 3d-6th days after exposure
Latent time of "elevator" reaction		
Pulse frequency	Decrease	Increase
Respiration frequency	Usually an increase	Decrease
Bioelectric activity:		
Cortical regions	Activation	Inhibition on 3d-4th days
Reticular formation	No change	Pronounced activation on the 3d-4th days

exposure to it, suprathreshold, one-time, 1-hour inadequate exposure of the body surface to this noise (the organs of Corti of the experimental animals were destroyed) elicited biphasal lengthening of the latent time of the reaction to the same stimulus, with the first phase occurring on the day of sound exposure and the second phase occurring on the 3d-6th days after exposure, which in the opinion of the authors is a consequence of a transition of the response from the analyzer level to the level of physicochemical chain reaction. We can also see from Table 6 that while the pulse frequency decreases in response to adequate noise stimulation, it increases in response to inadequate stimulation. We can also see distinct differences in the respiratory frequency and in the EEG's recorded from cortical regions in the reticular formation. The authors point out that depending on differences in the means of perception of sounds and the pathways of their propagation within the organism, the nature of their action upon body functions changes. On the whole, the nature of the action of inadequately perceived acoustic stimuli is similar to the previously studied nature of action of low frequency ultrasound perceived by man, rats and rabbits through the entire body surface without participation of the hearing organ. This action has two phases, with the second phase falling on the 4th day after exposure. The second phase, which coincides in time with biochemical changes, is obviously associated with development of chain reactions. As far as the particular ways inadequate acoustic stimuli and ultrasound influence autonomic functions, particularly the pulse frequency, are concerned, they are associated with differences in the pathways of propagation of sensory effects, and with absence of ephaptic* influences on the nucleus of the vagus nerve when acoustic and ultrasonic oscillations are inadequately perceived.

Attention should also be turned to the fact that these data actually extend the Vegel'-Gil'demeyster curve (see Figure 25) in the direction of greater frequencies, such that we can determine the location of point Д at which auditory sensitivity, which decreases as the oscillation frequency increases, intersects the curve for inadequate sensitivity to acoustic stimuli. An important property of this point is that within its vicinity, adequate and inadequate sensitivity are quantitatively equal, and a stimulus located at this point has a double effect upon the body--adequate and inadequate. Beginning at this point, adequate sensitivity becomes less inadequate. This point is also apparently the starting point for reading ultrasound values on the Vegel'-Gil'demeyster curve. Another point on the Vegel'-Gil'demeyster curve is point A, at which the two branches of the curve intersect on the left, in the low frequency range. Infrasonic oscillations obviously begin left of this point. Stimuli corresponding to this point are also of considerable interest to physiologists and ergonomists because they would affect both adequate and inadequate sensitivity simultaneously. Beginning with this point, and to the left of it along the trend of the Vegel'-Gil'demeyster curve, sensitivity to inadequate infrasonic stimulation becomes greater than sensitivity to adequate auditory stimulation.

Significance of the Intensity and Time of Action of Hygienic Factors to Formation of Responding Reactions

Going on to the problems associated with the intensity and time of action of hygienic factors upon the body and formation of responses to these effects, we must keep in mind that the overall quantitative evaluation of this interaction must account for three types of quantitative dependencies: intensity-effect, time-effect and intensity-time-effect. Investigation of these dependencies showed that the intensity-effect association may manifest itself in different ways. In some cases a response to the action of a hygienic factor increases in proportion to growth of intensity (concentration, dose), which is graphically represented by a straight line. In other cases the intensity-effect dependence manifests itself more intricately: Slight changes in intensity may elicit greater changes in the response, and vice versa. At the same time the curve describing the intensity-effect dependence may have an S shape in many cases (Figure 26). As far as the time-effect dependence is concerned, it has the same form as the intensity-effect dependence, since on the whole the time of action of any hygienic factor is proportional to the intensity of action, which was demonstrated quite well in conditioned reflex experiments performed by I. P. Pavlov's colleagues. Intensity-effect and time-effect dependencies of this sort may be interpreted as a manifestation of the laws of optimum and pessimum stimulation (as defined by N. Ye. Vvedenskiy). The case in which the expressiveness of a response to a hygienic factor grows as intensity or time of action increases is nothing more than the preliminary stage of parabiosis, which is in fact typified by growth in a responding reaction as the intensity or time of stimulation grows. In this case the operating hygienic factor remains at a weak stimulation level as the intensity (dose,

*Ephaptic influences are those which arise owing to the proximity of excited formations. In this case an ephaptic influence would arise owing to the proximity of the centers of the vagus and auditory nerves to the medulla oblongata.

concentration) or time of its action increases. If the nature of the reaction is described by a sigmoid curve, the response subsequently achieves the balanced stage of Vvedenskiy's parabiosis, and as the strength and time of action of the hygienic factor increase, the expressiveness of the response does not change; then the sigmoid curve reaches a plateau. Of course, it is much more difficult to reveal Vvedenskiy's laws in the intact organism than in an isolated nerve or a neuromuscular preparation owing to mutual superimposition of responses occurring simultaneously at different levels; nevertheless the sigmoid curve is obviously nothing other than an expression of the optimum and pessimum.

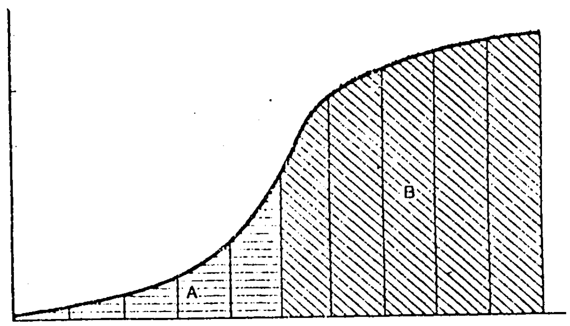


Figure 26. Sigmoid Dependence of a Response on the Intensity of an Effect: Area A--growth in response; B--gradual decrease of the response's increment during growth in intensity, and transition of the response to the balanced phase; ordinate--expressiveness of the response; abscissa--intensity (dose) of the operating factor

Because of mutual superimposition of reactions occurring at different levels of integration, the paradoxical phase of Vvedenskiy's parabiosis cannot be revealed in the intact organism in response to the action of hygienic factors, though in many cases the paradoxical phase can be revealed by measuring the latent time of reflex reactions or the intensity of responding reactions. It is always observed in relation to these indicators in research on the dynamics of conditioned reflex development in experimental animals subjected to the most diverse factors. We can cite as an example M. N. Konovalov's data (1965) from research on the biological action of low frequency ultrasound, and S. M. Pavlenko's data (1976) from research on the effects of chemical factors.

Thus we can conclude that although the intensity-effect and time-effect laws are masked by mutual superimposition of reactions occurring at different levels of integration, nevertheless detailed analysis can reveal their subordination to the general laws of the stimulation optimum and pessimum.

In regard to the relationship between the intensity and time of action of hygienic factors required for attainment of a certain response, for example a threshold response, a lethal outcome or some toxic effect manifesting itself as the beginning of illness or as certain changes in the state of certain body functions or systems, in all of these cases detailed analysis of the phenomena would show that they follow a hyperbolic law, usually expressed by the equation

$$i = \frac{a}{t} + b,$$

where i--intensity of action; t--time of action; a and b--constants.

Presence of constants a and b, which differ for different cases of the hyperbolic law's application and for different forms of effects, means that extensive research must be performed before the law can be established. However, the strictly mathematical form of the intensity-time-effect law permitted the French physiologist (L. Lapik) (1909) to develop a method that significantly simplifies determination of a concrete form of the hyperbolic law. As a strict mathematical curve, the hyperbola can be plotted on the basis of two points. Lapik found a method for determining these two points to be used in plotting a hyperbola. These points are the well known rheobase and chronaxie. The rheobase is defined as the threshold intensity of a long-acting factor of the surrounding or work environment, and chronaxie is defined as this factor's minimum time of action for achieving a threshold (or some other) effect at an intensity of action equal to double the rheobase. Braces in Figure 27 show the rheobase and chronaxie values. Using these points, we can plot an intensity-time curve for any effect and for any excitable formation. As we can see, Lapik's suggestion of the rheobase and chronoxie is nothing other than a means of mathematical simulation of the intricate process of determining the intensity-time-effect law, and the intensity-time-effect curve itself allows us to discern the relationship between development of a response to a certain effect and the particular features of the operating factor, and to predict, at any time, the reaction that forms in response to a certain effect. After the intensity-time-effect curve is established, we can use it in particular to predict the consequences of possible efforts to improve working conditions, and thus ensure their high usefulness, as had been done in relation to predicting the consequences of protective measures against radioactive effects. In the latter case this involved establishing the 50 percent lethal dose of ionizing radiation. It is, as we know, 500 r for general irradiation. Doses at which certain symptoms of radiation sickness arise have been established. Now a personal dosimeter keeping an exact record of the irradiation dose is furnished to all workers in all institutions in which exposure to ionizing radiation is possible. In these cases the intensity-time-effect law has enjoyed full application.

There are indications that hygienists are close to establishing a maximum load, beyond which a transfer to other work is mandatory, in relation to another hygienic factor--silicosis. In this case a relationship has been established between accumulation of a dangerous quantity of stone dust in the lungs on one hand and the dose of this dust in the atmosphere and the time of working under these conditions on the other. Establishment of this relationship has made it possible to determine the safe time of work in a work zone subjected to stone dust; this is done by keeping a record of the dose and the time of presence within its zone of action.

It follows from the above that by keeping track of the intensity and time of action of factors in the work and surrounding environment and by establishing the intensity-time-effect curve, we can create new and important prospects for studying their biological action and the basic principles of hygienic prediction of the consequences of preventive and, in particular, ergonomic measures.

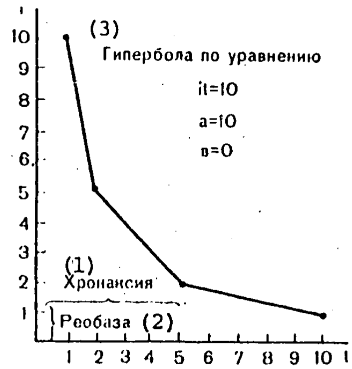


Figure 27. The Hyperbolic Law

Key:
1. Chronaxie
2. Rheobase
3. Hyperbola for $it = 10$, $a = 10$, $b = 0$

Biological science has established another form of nonspecific interaction between the organism and hygienic factors, namely the general adaptation syndrome discovered by Selye. This syndrome is a stress reaction, and according to Selye himself, it may be defined as the sum total of the general features of the reactions of living organisms to all stimuli that have a tendency to disturb the dynamic homeostasis of psychological, biochemical and physiological processes. If stress factors operate intensively and for a long period of time, they will elicit a large number of reactions which Selye referred to as the general adaptation syndrome. These reactions fall into three phases: the alarm reaction, the resistance phase, and exhaustion.

Particular Dynamics of the Body's Reaction to Hygienic Factors

The first thing that should be pointed out here is that formation of responses to production factors requires a certain amount of time. This time, which extends from the start of action of a particular effect to the moment a response to it arises, has come to be called the latent time. It may vary from fractions of a second to many hours and even days, depending on the nature of the effect and of the body's response. Because it is during the latent period that all aspects of the body's response are formed, this latent time is believed to be one of the most important physiological indicators of response formation. In the intact organism, a short time is typical for formation of responses to effects perceived by exteroreceptors (eye, ear, receptors of pain, touch, heat and cold, olfactory and vestibular analyzers and so on). The latent time of these reactions (Table 7) is within the limits of the duration of responses associated with controlling production equipment.

As we can see from Table 7, visual and auditory receptors react the fastest, the vestibular analyzer reacts more slowly, the temperature analyzer reacts even more slowly, and the slowest reaction is exhibited by the olfactory analyzer. Concurrently the slowest reactions arise in response to radiated heat and cold. The receptors for these effects are in subcutaneous veins.

Table 7. Latent Time for Different Sensomotor Reactions

Reflex Reactions	Latent Time, msec	Authors
Tendon reflexes		
Hand extensor	65-70	
Knee-jerk reflex	70-100	S. I. Gorshkov,
Achilles reflex	120-190	Ye. G. Zhakhmetov
Biceps relfex	140-160	
To painful electrocutaneous stimulation	100-120	
To auditory stimulation	140-160	
To light stimulation		
Central part of retina	160-180	S. I. Gorshkov
Periphery of retina	180-220	
To auditory and light stimulation, with a choice (differentiation)	220-340	
To painful thermal stimulation	360-400	
To thermal contact stimulation	500-800	
To cold contact stimulation	350-450	S. I. Gorshkov, N. A. Kokhanova
To thermal radiant stimulation	1000-1400	
To cold radiant stimulation	2-5 min	
Vestibulomotor reactions		
To positive angular acceleration	260-270	
To the right	260-270	
To the left	270-280	
To negative angular acceleration		S. I. Gorshkov
To the right	250-260	A. V. Kolesnikova
To the left	270-280	G. A. Antropov
To positive linear acceleration	360-380	
To negative linear acceleration	320-340	
To olfactory stimulation by vapor from:		
(Relin)	900-1000	S. I. Gorshkov,
Linoleum	700-800	G. A. Pronin
Wood chip panels	900-1000	

Responses by skeletal muscles are fast. As a counterweight to this, we can cite the fact that responses by the heart taking the form of change in pulse frequency, the size of the vessel lumen, blood pressure, skin temperature and sweating--that is, responses controlled by the autonomic nervous system--are slower. Their latent times are in the seconds. These data, shown in Table 8, were compiled from material in a candidate dissertation written by Yu. F. Khvorov for the Ivanov Medical Institute (1973).

Table 8. Latent Times of Some Autonomic Reflexes

Indicator Analyzed	Latent Time, Sec	Indicator Analyzed	Latent Time, Sec
Latent time of the cardio-ocular reflex in response to change in pulse frequency	5.2 ± 0.3	Latent time of vessel lumen dilation reaction in response to dosed physical load	7.8 ± 1.0
Latent time of change in pulse frequency in response to dosed physical load	1.2 ± 0.1	Latent time of vessel lumen constriction reaction in response to dosed physical load	8.9 ± 0.9
Latent time of sweating reaction in response to dosed physical load	4.3 ± 0.2		

Formation of responses to the effects of factors perceived by other than the sense organs proceeds even more slowly, as can be deduced from the time of arisal of particular responses in different body systems. In this case the intensity of the operating factor also plays an important role in the rate of formation of the response. As we can see from Figure 28, which is based on R. M. Nikol'skaya's data (1978) and which shows the dynamics behind the concentration of hexuronic acid in the aorta of albino rats poisoned by inhalation of dimethyldioxane (as percentages of control), when the dose is large (0.35 mg/liter) a significant increase in hexuronic acid does not occur until the 19th day after poisoning, while with a smaller dose (0.04 mg/liter) a significant increase in hexuronic acid is not observed until the 91st day following the start of poisoning. This figure also shows the phasal nature of the change--the difference in the direction of changes occurring in response to different doses of the operating factor. This is an indication that phases of compensation and toxic action follow one another.

However, the phasal nature of certain changes may also be the result of transition of formation of a response from one functioning system to another. Such a transition occurs, for example, in response to radioactive emissions. Immediately following irradiation, a response arises in pronounced form at the level of the central nervous

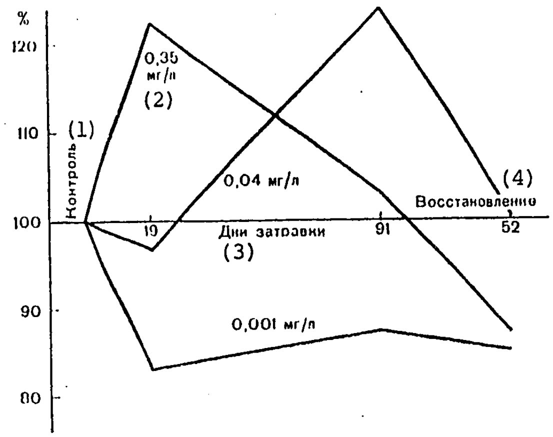


Figure 28. Dynamics of the Concentration of Hexuronic Acid in the Aorta of Rats Inhaling Dimethyldioxide (Percent of Control)

Key:
1. Control
2. Mg/liter
3. Days of poisoning
4. Recovery

system, as may be deduced from the dynamics of the latent time of the reflex reactions. However, following a latent period of 2-3 weeks these changes in the state of the central nervous system give way to other manifestations of radiation sickness, ones manifesting themselves in the particular dynamics of changes in blood composition. The transition of the response's formation from the level of the central nervous system to the level of physicochemical reactions is also observed in relation to the biological action of low frequency ultrasound and other hygienic factors.

We can see from the above that the dynamics behind formation of the body's responses to factors in the work and surrounding environment are extremely crucial to an understanding of their biological action, and thus their hygienic standardization, which is at the basis of any protective measures, including ergonomic , that may be developed.

Laws of the Body's Adaptation to Hygienic Factors Based on Our Ideas About the Body's Functional Systems

Some laws governing formation of the body's responses to factors in the work and surrounding environment were presented above. However, if we look at these dependencies of the body's reactions, taken separately, we are unable to discern the pathway for which integration and interaction of different systems and organs in their responses to an effect. This process has been viewed differently in different stages of the development of biological and medical science. There was a time when our understanding of this process was based on the idea that individual organ systems act independently during formation of a response to an effect. This is the well known theory of cellular pathology created by R. Virchow. Starting with a false interpretation of the cellular theory, from the very beginning Virchow rejected the organism's integrity and its unity with the environment, and he asserted that a complex organism is a set of cells reacting independently to environmental factors. Owing to the efforts of, especially, Soviet physiologists, pathophysiologists, clinicists and hygienists, this idea gradually gave way to growing acceptance of the notion that the organism is in unity with the environment, that the organism's reactions are integrated. The reflex principle of integration was founded on this idea.

The theory of functional systems developed by P. K. Anokhin is a further development of the idea that the organism's reactions to environmental factors are integrated, and of the reflex principle of integration. The essence of this theory is that any compensation of the body's disturbed functions--that is, recovery of its homeostasis--can be achieved only by mobilization or integration of a significant number of physiological components, located in different parts of the central nervous system and the working periphery but always united functionally on the basis of the final adaptive effect needed at the given moment of interaction with factors of the surrounding and work environment.

This vast functional association of variously located structures and processes, existing with the purpose of producing an adaptive effect, is what Anokhin called the "functional system." Functional systems may be inborn (species-specific), acquired in the course of individual development and created for one-time reaction to some single effect, a stress factor for example. Inborn functional systems include those supporting the organism's vitally important functions--respiration, circulation, digestion, reproduction and many others, while acquired functional systems are those which support the habits of the organism and which are developed through training and learning. An association of many body systems may be created in extreme situations in response to stress factors. Functional systems may occur at different levels of integration: the population, the organism, the system, the organ, the tissue, the cell and the molecule. The population level of integration occurs whenever the effect of a factor of the surrounding and work environment directly affects the population of an entire region and when responses are generated simultaneously in many organisms within this region. An example of such reactions would be adaptation by people moving to northern regions for a long period of time. Reactions at the level of the organism include changes in its performance and its health, for example in response to recent acceleration. The systemic level may be represented by adaptive changes in a certain isolated system or simultaneously in a number of functions--for example the cardiovascular system and the thermoregulatory system. Understanding the cellular level of integration raises no difficulties. In this case we have in mind the responses of cellular structures, mitochondria for example. Research at the molecular level is presently the main achievement of biological and medical science. Memory processes and transmission of hereditary information are associated with the molecular mechanisms of nucleic acids.

We can see from this section that adaptation to the effects of factors in the work and surrounding environment occur in the organism with a consideration for the informativeness of the operating factors, the laws governing the intensity and time of their action, the particular dynamics behind formation of responses and the mechanism of integration of the manifestations of all particular aspects of the studied factors. By considering all of these general characteristics of the organism's reactions to hygienic factors, we can scientifically substantiate standards for such factors and develop ergonomic recommendations concerned with the design of production equipment and the organization of workplaces.

The Ergonomic Approach to Standardizing Factors in the Work Environment

One of the principal requirements of industrial ergonomics is the premise foreseeing that the design of machines and production equipment must not be a source of undesirable sanitary and hygienic working conditions. What this means concretely is that equipment design must correspond with hygienic requirements in regard to maintaining the sanitary and hygienic conditions of the workplace at the level of the standards established by public health legislation (S. I. Gorshkov, 1971).

In accordance with this premise, an ergonomic approach to standardizing the factors of the work environment must regard the following: In the case conditions deviating from the established standards are discovered in a particular production operation, steps must be taken to improve the design of the production equipment, such that the standards for the involved hygienic indicators would be met.

According to GOST [All-Union State Standard] 12.0.003-74, hazardous and harmful production factors affecting a worker at his workplace are subdivided into the following groups depending on their nature of action: physical, chemical, biological and psychophysiological.

Physical factors are in turn subdivided into the following subgroups: the temperature of equipment and material surfaces; air temperature, humidity and circulation, its ionization, and its dust and gas content; levels of noise, vibration, infrasonic oscillations, ultrasound, static electricity, electromagnetic emissions, and the intensity of electric and magnetic fields; a dangerous amount of voltage carried by an electric circuit that may come in contact with the human body; natural and artificial lighting; brightness of light; direct and reflected glare; pulsations in light flux; contrast; level of ultraviolet and infrared radiation.

The chemical factors group is subdivided into the following depending on the nature of the effect on the human body: general toxic, irritant, sensitizing, carcinogenic, mutagenic and influencing the reproductive function; these factors are also subdivided in relation to the means by which they enter the human body: through the respiratory tract, the digestive system or the skin.

The biological factors group includes biological objects which cause injury to workers or make them ill: microorganisms (bacteria, viruses, *Rickettsia*, spirochetes, fungi, protozoans) and macroorganisms (plants and animals).

The psychophysiological factors group is subdivided into the following subgroups in terms of their nature of action: physical overloads (static, dynamic), hypodynamia, psychoneural overloads (mental overexertion, overexertion of analyzers, monotony of labor, emotional overloads).

Many of these factors, especially biological and psychophysiological factors, do not have clear maximally permissible levels of expression, while the norms of some others require clearer definition.

Data on hygienic indicators associated most often with the workplace are presented below. If a given factor is not dependent upon equipment design, its indicators at the workplace must be within optimum limits.

Air in the Work Zone

This section is based on SN [Construction Norm] 245-71 and GOST 12.1.005-76, which contain the general sanitary and hygienic requirements on the microclimate and on the concentration of toxic substances in the air of the work zone.

The microclimate is represented by a complex of physical characteristics imparted to an enclosed space by meteorological factors; these physical characteristics predetermine thermal exchange between the body and the environment of the workplace, and they include the temperature of the air, its humidity and circulation, and the temperature of surrounding objects (equipment and structures within the room). Microclimate standards are closely associated with the heaviness of labor.

In accordance with the existing classification, all jobs done at enterprises are subdivided into three heaviness categories.

Light physical work (category I) is represented by jobs performed while sitting or standing, or jobs associated with walking but not requiring systematic physical exertion, or the lifting and carrying of heavy loads; energy expenditures have a maximum of 150 kcal/hr (172 j/sec).

Moderately heavy physical work (category II) is represented by jobs involving forms of activity requiring energy expenditure from 150 to 200 kcal/hr (172-232 j/sec)--category IIa, and from 200 to 250 kcal/hr (232-250 j/sec)--category IIb. Category contains jobs requiring constant walking, and jobs performed standing or sitting but not requiring movement of heavy loads. Category IIb contains jobs associated with walking and with carrying small loads (up to 10 kg).

Heavy physical work (category III) is represented by jobs associated with systematic physical exertion, and particularly with continual movement and transport of sizeable loads (over 10 kg); the energy expenditures are greater than 250 kcal/hr (293 j/sec).

Optimum microclimatic indicators for the workplace are shown in Table 9.

Workplace requirements that need to be considered include the temperature of heated surfaces, equipment and enclosures, which must not exceed 45°C; for equipment having an internal temperature of 100°C or lower, the surface temperature must not exceed 35°C.

If for technical reasons it is impossible to meet these temperature requirements near the sources of significant radiant and convective heat (heating and melting units, molten and red-hot metal and so on), measures to protect workers from possible overheating must be foreseen: water-air showers, screening, highly dispersed spraying of water on irradiated surfaces, radiator-cooled cabs or surfaces, break rooms and so on.

Air showers must be foreseen at permanent workplaces at which workers are subjected to radiant heat totaling 300 kcal/m^2·hr and more.

Hand warmers must be foreseen at workplaces involving continual contact with wet and cold objects (for example frozen meat cutting and fish dressing).

Table 9. Optimum Norms for Temperature, Relative Humidity and Rate of Movement of Air in the Work Zone of Production Buildings (GOST 12.1.005-76)

Season of the Year	Work Category	Temperature, °C	Relative Humidity, %	Air Movement Rate, m/sec Not More Than
Cold and transitory periods of the year (outside air temperature below +10°C)	Light--I	20-23	60-40	0.2
	Moderately heavy--IIa	18-20	60-40	0.2
	Moderately heavy--IIb	17-19	60-40	0.3
	Heavy--III	16-18	60-40	0.3
Warm part of the year (outside air temperature +10°C and higher)	Light--I	22-25	60-40	0.2
	Moderately heavy--IIa	21-23	60-40	0.3
	Moderately heavy--IIb	20-22	60-40	0.4
	Heavy--III	18-21	60-40	0.5

As Zinchenko et al. (32) validly note on the basis of published data, a dynamic climate typified by certain variations in its indicators that train the body's thermoregulator apparatus and improve the tone of the nervous system should be created in production. It has been established that "mild, comfortable temperatures" and "hothouse conditions" may operate as a monotonous stimulus, eliciting an inhibitory state. However, the difference between the air temperature at the floor surface and the temperature at head level must not be more than 5°C.

A discussion of microclimate requires mention of an ergonomic indicator: On the average, a 1°C deviation of air temperature from the standards corresponds to a 1 percent decrease in labor productivity (19).

The group of chemical factors encountered in the air of a work zone is represented by toxic substances and aerosols of predominantly fibrogenic action. Hygienists of recently developed maximally permissible concentrations for 646 toxic substances and 57 aerosols. In view of the large numbers of substances contained in these two groups, we will not list them here, instead referring the reader to the GOST cited above.

We do believe it necessary, however, to turn the reader's attention to the approach which must be taken when several toxic substances exhibiting like action are simultaneously present in the air of the work zone. In this case the sum of the ratios between the actual concentrations of each of them (C_1, C_2, ..., C_n) in the air of the work space and their PDK's [maximum permissible concentrations] (PDK_1, PDK_2, ..., PDK_n) must not exceed unity:

$$\frac{C_1}{PDK_1} + \frac{C_2}{PDK_2} + \cdots + \frac{C_n}{PDK_n} \leqslant 1.$$

As a rule, toxic substances of like action have similar chemical structure and nature of biological action upon the human body (B. D. Karpov, 1976).

When several toxic substances of unlike action are simultaneously present in the air of the work zone, the PDK's are treated in the same way as if they were acting individually.

Illumination

This section is based on standards SNiP II-A.8-72 and SNiP II-A.9-71, and papers written by F. M. Chernilovskaya (1971, 1976). In this case we deliberately limited our standard lighting indicators to visual work classes I-VI, which are encountered most frequently at stationary workplaces.

The productivity of each worker is directly dependent on the efficiency of the particular form of lighting and its intensity at the workplace, since these are factors governing the effectiveness with which the visual and motor systems function, and the state of the central nervous system.

Three forms of lighting are used in production buildings: natural, artificial and combined.

The action of natural light upon the human body is typified by diversity of form and level: We encounter biological action, which is a product of phylogenesis and ontogenesis, psychological action responsible for the direct visual relationship to the environment, and the effect of natural light on production, dependent on the uniformity of illumination.

Natural lighting is achieved in production buildings through lateral light openings, windows (lateral lighting) and through overhead light openings and lanterns (overhead lighting). Combined lighting is used in multiple-bay buildings: Lateral lighting is provided to places in a building with overhead lighting located farthest from the lanterns.

Combined lighting is employed in buildings that do not provide enough natural light for visual work--tnat is, inadequate natural lighting is always supplemented by artificial lighting.

The level of natural illumination at workplaces is defined by the coefficient of natural illumination (e), and it indicates what proportion diffuse light from the sky contributes to illumination at a point of evaluation within a room. As with illumination in general, this coefficient is standardized primarily depending on the nature of the visual work done (Table 10).

Artificial lighting is subdivided into general, local and combined. General lighting is intended to illuminate the entire room; it may be uniform (when jobs of the same kind are performed throughout the entire area of the room and when the density of workplaces is high) or localized (when bulky shadow-casting equipment is present and when directional light is required). Local lighting is intended to illuminate only the work surfaces. Combined lighting consists of general and local. Its best use is with high precision jobs, and when fixed or variable directional lighting is required.

Table 10. Values of *e* for Production Rooms in Keeping With the "Work Surface Conditions" (SNiP II-A.8-72)

Characteristics of Visual Work	Least Dimension of Object to be Distinguished, mm	Visual Work Class	Value of *e* in Presence of Natural Illumination: Overhead and Combined	Lateral
Work done:				
Highest precision	Less than 0.15	I	10	3.5
Very high precision	0.15-0.3	II	7	2.5
High precision	0.3-0.5	III	5	2
Moderate precision	0.5-1	IV	4	1.5
Low precision	1-5	V	3	1
Rough	More than 5	VI	2	0.5

Luminescent lighting is becoming universally accepted in modern production to illuminate workplaces, no matter what the method for ensuring standard illumination in the work zone. This problem is solved uniquely in each concrete case. An example of such a solution can be found in Chapter V of this collection--development of a new workplace for a sewing machine operator.

Luminescent lamps are low-pressure gas-discharge mercury lamps, the inside surface of which is coated with a layer of phosphor. When the lamp is turned on, electric energy in the mercury vapor is converted to the energy of shortwave ultraviolet emissions with 254 and 185 nm wavelengths. Phosphor transforms ultraviolet radiation into visible light, the spectral characteristics of which depend on the composition and method of preparation of the phosphor. High economy is an advantage of luminescent lamps: Their light output is 324 times greater than that of incandescent lamps. Moreover luminescent lamps have many hygienic advantages over incandescent lamps. Their glowing surface area is larger, meaning that they provide more-uniform light within the field of view of the workers. They produce little radiant heat. Their emission spectrum is close to that of natural daylight (for LYe and LDTs lamps), and hence they produce an almost-natural color. Luminescent lamps create favorable conditions for illumination of the visual organs as well as the human body as a who[illegible]. Luminescent lighting helps to reduce eye fatigue, to improve the functional st[illegible] of the central nervous system, to raise labor productivity and to improve pr[illegible]ct quality.

There has been interest shown in recommendations by F. M. Chernilovskaya (1971) to vary the intensity of illumination in a production room during the day, as a reflex factor improving the general performance of the individual, delaying the onset of fatigue and relieving it if it is already developing. These recommendations now await their technical development.

Different types of luminescent lamps distinguished by the spectral distribution of the light flux are now being produced.

1. Daylight lamps (LD) are close in the spectral characterstics of their emissions to those of diffuse daylight.

2. Daylight lamps with improved color reproduction (LDTs) are closer to natural light in the spectral composition of their emissions.

3. Type LYe luminescent lamps are closest to the spectrum of natural sunlight.

4. White lamps (LB) produce emissions with a lower concentration of blue-violet rays than daylight lamps.

5. The emission spectrum of cool-white lamps (LKhB) occupies an intermediate position between those of LB and LD lamps.

6. Warm-white lamps (LTB) produce a light with a pinkish white hue.

7. DRL lamps (mercury arc luminescent) are high-pressure lamps with corrected chromaticity intended for rooms with a ceiling height greater than 12-14 meters; their use would be unsuitable in rooms less than 6 meters high.

8. DRI lamps are high-pressure mercury lamps to which metal iodides have been added. They were developed out of DRL lamps, the chromaticity of their emissions is improved, and they are one of the most economical sources of general-purpose light.

Luminescent lamps are used predominantly in multiple light fixtures. This makes special wiring patterns which reduce pulsation of the light flux possible.

Table 11 shows the norms for the intensities of artificial illumination at workplaces, in correspondence with the visual work class and the contrast of the object of discrimination in relation to its background.

As a rule, gas-discharge lamps (luminescent lamps, DRI and DRL lamps) should be used in a general lighting system for production rooms in which class I-V jobs are done.

A combined lighting system should be used with class I-IV, Va and Vb work.

A general lighting system can be used when it is technically impossible or unfeasible to install local lighting.

As a rule, gas-discharge lamps should be used in general lighting within a combined lighting system, irrespective of the type of light source employed for local lighting.

The illumination provided to work surfaces by general light fixtures in a combined system must be 10 percent of the standard for combined lighting, but not less than 150 lux when gas-discharge lamps are used.

Table 11. Illumination Norms for Work Surfaces in Production Rooms (SNiP II-A.9-71)

Nature of Visual Work	Least Dimension of Object to be Distinguished, mm	Visual Work Class	Visual Work Subclass	Contrast of Object to be Distinguished in Relation to Background	Background Characteristic	Illumination, lux: Combined Lighting System	Illumination, lux: General Lighting System
Highest precision	Less than 0.15	I	a	Low	Dark	5000	1500
			b	"	Medium	4000	1250
				Medium	Dark		
			c	Low	Bright		
				Medium	Medium	3000	1000
				High	Dark		
			d	Medium	Bright		
				High	"	1500	400
				"	Medium		
Very high precision	0.15-0.3	II	a	Low	Dark	4000	1250
			b	"	Medium		
				Medium	Dark	3000	750
			c	Low	Bright		
				Medium	Medium	2000	500
				High	Dark		
			d	Medium	Bright		
				High	"	1000	300
				"	Medium		
High precision	0.3-0.5	III	a	Low	Dark	2000	500
			b	"	Medium	1000	300
				Medium	Dark		
			c	Low	Bright		
				Medium	Medium	750	300
				High	Dark		
			d	Medium	Bright		
				High	"	400	200
				"	Medium		
Moderate precision	0.5-1	IV	a	Low	Dark	750	300
			b	"	Medium	500	200
				Medium	Dark		
			c	Low	Bright		
				Medium	Medium	400	150
				High	"		

			c	Low	Bright		
				Medium	Medium	400	150
				High	"		
			d	Medium	Bright		
				High	"	300	150
				"	Medium		
Low precision	1-5	V	a	Low	Dark	300	200
			b	"	Medium	200	150
				Medium	Dark		
			c	Low	Bright		
				Medium	Medium	-	100
				High	Dark		
			d	Medium	Bright		
				High	"	-	100
				"	Medium		
Rough (very low precision)	More than 5	VI	-	Independent of background characteristic and object's contrast in relation to the background		-	100

Local lighting requires light fixtures with opaque reflectors with a shielding angle not less than 30 degrees.

Reflectors with a shielding angle of 10-30 degrees may be used in light fixtures if they are located below the worker's eye level.

Noise

Noise is a factor that accompanies almost all production operations today, and its presence remains a reality despite the efforts by designers and developers to eliminate or at least limit it.

There is an extensive Soviet and foreign literature on the effects of noise on the human body. The pattern of its influence is distinguished by high polymorphism: from its primary influence upon the central nervous system and the accompanying broad spectrum of asthenic states and action upon almost all body systems, to organic injury of the auditory nerve.

According to published data, noise can reduce labor productivity by 60 and even 40 percent.

The general requirements on safe noise levels are spelled out in GOST 12.1.003-76. This standard establishes the classification of different noises, the permissible noise levels at workplaces and the general requirements associated with the noise characteristics of machines, mechanisms, transportation resources and other equipment (referred to in the subsequent discussion as machines) and with noise protection.

Noise is subdivided in relation to its spectrum into wideband, having a continuous spectrum with a range of more than one octave, and tonal, with audible discrete tones in its spectrum. Noise is said to be tonal if the intensity of one third-octave frequency band is not less than 10 db greater than that of the adjacent bands.

Noise is subdivided in relation to its temporal characteristics into constant, for which the acoustic intensity does not vary by more than 5 db·A during an 8-hour work day, and variable, for which the acoustic intensity varies by not less than 5 db·A in the course of an 8-hour work day.

Variable noise is subdivided in turn into: continuously fluctuating in time; intermittent, with acoustic intensity dropping sharply to the level of background noise, and with intervals of 1 second and more in which the noise intensity remains constant and above the level of background noise; pulsed, consisting of one or several acoustic signals, each with a duration less than 1 sec and with their acoustic intensities differing by not less than 10 db.

The equivalent (in terms of energy) acoustic intensity, in db·A, as defined by GOST 20445-75, characterizes variable noise at workplaces.

Wideband noise is characterized by permissible levels of acoustic pressure in octave frequency bands, acoustic intensities and equivalent acoustic intensities in db·A at the workplaces (Table 12).

Table 12. Permissible Acoustic Pressure Levels and Acoustic Intensities at Permanent Workplaces in Industrial Enterprises (GOST 12.1.003-76)

Workplaces	Acoustic Pressure Levels, db, in Octave Bands With Following Mean Geometric Frequencies, Hz								Acoustic Intensities and Equivalent Acoustic Intensities, db·A
	63	125	250	500	1000	2000	4000	8000	
The rooms of design offices, accountants, computer programmers, laboratories for theoretical work and for processing experimental data, patient admission rooms in medical centers	71	61	54	49	45	42	40	38	50
Administrative rooms, offices	79	70	68	58	55	52	50	49	60
Observation and remote control rooms:									
Without vocal telephone communication	94	87	82	78	74	73	71	70	80
With vocal telephone communication	83	74	68	63	60	57	55	54	65
Precision assembly rooms and sections; typing offices	83	74	68	63	60	57	55	54	65
Laboratories intended for experimental work, rooms containing noisy computer units	94	87	82	78	75	73	71	70	80

Permanent workplaces and work zones in production rooms and on the enterprise territory	99	92	86	83	80	78	76	74	85
Permitted until 1 December 1979 in conditions typified by high noise levels and requiring implementation of special noise reduction measures	103	96	91	88	85	83	81	80	90

Technical noise control resources can be applied with the purpose of reducing noise at the workplace to a permissible level: reduction of the sources of noise in machines, application of production processes satisfying the maximum permissible level requirements, structural soundproofing measures, remote control of noisy machines, mandatory use of personal protective resources by workers when the noise level at the workplace is greater than 85 db·A; organizational measures (sensible work-rest schedule, limitation of time workers are exposed to noise).

Vibration

Being a factor of the production environment, vibration is encountered in most industrial sectors: as a means of transferring energy to and acting upon a processed object (compaction, molding, pressing, drilling, loosening, transportation etc.), and as an accompanying factor of movable and permanently installed mechanisms making rotary or reciprocal motions. Oscillatory movement is created by oscillations of interacting equipment parts, the article being worked and other elements. In this connection the resulting oscillatory movement is aperiodic, and it often has a pulsating or jerky nature. Vibration is subdivided depending on the nature of contact between the worker's body and vibration into local, transmitted through the worker's hands, and general, transmitted through a supporting surface to the standing or sitting worker. Certain jobs may cause a worker to be exposed to combined vibration, with local or general vibration dominating.

Vibration has an unfavorable mechanical influence upon the body at 3-30 Hz in connection with the presence of resonance peaks related to both the entire body as a whole and individual parts of it; it is also connected with the position of the worker during work. As the oscillation frequency rises (above 30 Hz), mechanical transmission of vibration over the human body weakens. In this connection local nervous and reflex disturbances begin to dominate (vascular, neuromuscular, skeleto-articular and other disturbances).

While local low intensity vibration has a favorable action upon the human body and is employed in medicine, intensive and prolonged exposure to vibration in production conditions leads in a number of cases to development of occupational pathology--vibration disease.

When a worker is subjected to general vibration of varying parameters, pronounced changes occur in his central and autonomic nervous systems, cardiovascular system, metabolic processes and vestibular apparatus.

Restrictions on vibration at the workplace can be found in the following guidelines: local--GOST 17770-72 and others, general--SN 245-71, 1102-73 (tables 13 and 14). In addition there are now a number of narrow-profile public health norms applicable to agricultural and motor transport mechanisms, to seagoing and river vessels, to railroad transport and so on.

Table 13. Permissible Vibration Levels for Hand-Operated Machines (GOST 17770-72)

(1) Средние геометрические частоты октавных полос, Гц	(2) Граничные частоты октавных полос, Гц		(5) Допустимая колебательная скорость	
	(3) нижние	(4) верхние	(6) действующие значения, м/с	(7) уровни действующих значений, дБ
8[1]	5,6	11,2	$5{,}00 \cdot 10^{-2}$	120
16	11,2	22,4	$5{,}00 \cdot 10^{-2}$	120
31,5	22,4	45	$3{,}50 \cdot 10^{-2}$	117
63	45	90	$2{,}50 \cdot 10^{-2}$	114
125	90	180	$1{,}80 \cdot 10^{-2}$	111
250	180	355	$1{,}20 \cdot 10^{-2}$	108
500	355	710	$0{,}90 \cdot 10^{-2}$	105
1000	710	1400	$0{,}63 \cdot 10^{-2}$	102
2000	1400	2800	$0{,}45 \cdot 10^{-2}$	99

[1] In the octave band with a mean geometric frequency of 8 Hz, only the oscillatory speed of hand-operated machines with a turning or cycling rate less than 11.2 per second is considered.

Key:

1. Mean geometric frequencies of octave bands, Hz
2. Limiting frequencies of octave bands, Hz
3. Lower
4. Upper
5. Permissible oscillating speed
6. Virtual values, m/sec
7. Intensities of virtual values, db

Table 14. Permissible Values for Workplace Vibration Parameters (SN 245-71)

(1) Для колебаний с несколькими гармоническими составляющими или сплошным спектром			(6) Для гармонических и полигармонических колебаний	
(2) среднегеометрические и граничные (в скобках) частоты октавных полос, Гц	(3) среднеквадратическое значение колебательной скорости		(7) частота, Гц	(8) амплитуда (пиковое значение) перемещения, мм
	(4) величины, мм/с	(5) уровни (дБ) относительно порога $5 \cdot 10^{-5}$ мм/с		
2 (1,4—2,8)	11,2	107	1,4	3,1100
			1,6	2,2200
			2,0	1,2800
			2,5	0,7300
			2,8	0,6100
			3,2	0,4400
4 (2,8 — 5,6)	5,0	100	4,0	0,2800
			5,0	0,1600
			5,6	0,1300
8 (5,6 — 11,2)	2,0	92	6,3	0,0900
			8,0	0,0560
			10,0	0,0450
			11,2	0,0410
16 (11,2 — 22,4)	2,0	92	12,5	0,0360
			16,0	0,0280
			20,0	0,0225
			22,4	0,0200
			25,0	0,0180
31,5 (22,4 — 45)	2,0	92	31,5	0,0140
			40,0	0,0113
			45,0	0,0102
			50,0	0,0090
63 (45 — 90)	2,0	92	63,0	0,0072
			80,0	0,0056
			90,0	0,0050

Key:

1. For oscillations with several harmonic components or with a continuous spectrum
2. Mean geometric and limiting (in parentheses) frequencies of octave bands, Hz
3. Mean square value of oscillating speed
4. Virtual value, mm/sec
5. Intensity (db) relative to a threshold of $5 \cdot 10^{-5}$ mm/sec
6. For harmonic and polyharmonic oscillations
7. Frequency, Hz
8. Movement amplitude (peak value), mm

Preventive measures aimed at reducing the effects of vibration upon the worker's body should primarily include replacement of production processes characterized by dangerous vibrations with safe processes, and eliminating the worker's contact with vibration or its influence upon him. There is a boundless range of possibilities for inventiveness in this area. Effective ways to reduce vibration include developing tools producing lower vibration and requiring less muscle force for their operation, using various shock-absorbing devices and subjecting existing equipment to planned preventive maintenance. Special emphasis should be laid on hygienic preventive measures that call for specific work-rest schedules depending on the intensity of vibration and the nature of the work, and on therapeutic and preventive measures aimed at raising the body's protective capabilities and performance.

Concluding this section on the ergonomic approach to standardizing factors in the production environment at workplaces, we should once again emphasize that the existing standards are being made stiffer as biological facts are accumulated. Evidence of this can be seen in the relative swiftness with which GOST's are superseded (5 years)--that is, the "man--machine--production environment" ergonomic system is undergoing continuous optimization. Industrial workers no longer need to be persuaded that failure to comply with the hygienic requirements of ergonomics means poorer working conditions, lower efficiency and labor productivity, and occupational pathology.

IV. PSYCHOPHYSIOLOGICAL CRITERIA OF ERGONOMICS

Dimensional Considerations at the Workplace

Correspondence of production equipment design and workplace organization with anthropometric data and man's physiological and psychological possibilities is an important prerequisite of optimizing interaction between man and equipment in a "man-machine" system. Assurance of this correspondence promotes better individual performance and higher effectiveness in fulfilling a production assignment.

It would be interesting to note that the design of production equipment in application to the "human factor" had been the focus of attention as far back as in the 15th century. Thus in 1473 Ellenbog noted that improperly designed equipment has an undesirable effect on human health (cited in (90)).

Today, owing to growing technical complexity of machines and mechanisms and the increase in their operating speeds, ergonomic requirements on equipment design and workplace organization are rising.

Physiological studies have shown that failure to comply with these requirements means work in an uncomfortable posture, arisal of undesirable physiological changes and earlier development of fatigue.

The principal work postures are sitting and standing. For a number of jobs the sitting-standing posture is the most suitable. When planning for a particular work posture, the designer should base himself on the size of the muscle forces applied, the precision and speed required of movements, the nature of the work being done, the minimum energy expenditure and the maximum productivity of movements.

Preference in the choice of the principal work posture should be given to sitting over standing. A sitting posture is less tiring, since owing to a lower center of gravity over the supporting area, the body's stability is higher; this decreases the muscle tension needed to maintain the posture, hydrostatic pressure and the load imposed on the cardiovascular system. Work movements are more precise when the work is done while sitting. The amount of weight lifted during seated work must not exceed 5 kg.

Work standing up is found to be preferable when the operator must move about freely in the course of a shift, when the work involves production equipment such as grinders, milling machines, looms, heavy presses and so on, or when the work consists mainly of tuning or adjustment. When standing, the individual enjoys maximum field of view and maximum possibilities for locomotion; he can perform movements of greater amplitude, and he can generate larger forces (more than 10 kg). When a workplace is organized for work in standing position, controls and various indicators may be located along a broader front.

It should be kept in mind, however, that work in standing position increases the load on the muscles of the lower limbs and on circulatory organs, and it raises the pulse rate. Figure 29 shows the levels of muscle bioelectric activity in a relaxed standing position. Activity levels are designated, in decreasing order, by solid shading, cross-hatching, dots and crosses. As we can see from the figure, the muscles in the vicinity of the ankle joint exhibit the greatest activity: the tibialis interior, the peronius longus and especially the gastrocnemius. Muscle bioelectric activity is less pronounced in the vicinity of the knee joint, and even less so about the hip joint. Although the size of the recorded biopotentials is small in comparison with that at maximum possible tension, the tension of the muscles is nevertheless greater in standing posture owing to the high center of gravity and the small supporting area. As a result the energy expenditure associated with a standing posture is 6-10 percent greater than that of a sitting posture.

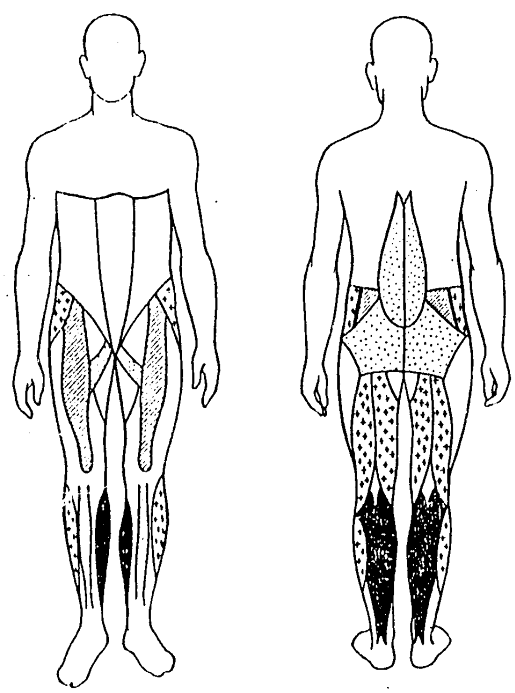


Figure 29. Muscle Bioelectric Activity During Relaxed Standing (26): A--front; B--back

During work, the posture is varied depending on the nature of the work movements associated with the particular production operation, and its physiological cost varies correspondingly. If the individual must work with his hands stretched forward, to maintain this posture he must raise the tension of muscles of the pectoral girdle and torso. Standing erect with hands stretched forward increases the tone of the biceps by 25 percent over that when the arms are lowered. Tone increases by 70 percent when a 2 kg weight is held in the hand (V. S. Farfel', 1956). When the body is slightly tilted the energy expenditures increase by 20 percent, while when it is tilted significantly they increase by 45 percent in comparison with a relaxed erect posture (O. H. Nemtsova, 1940).

Remaining in the same posture for a long period of time may be tiring to the body due to the constant static load imposed on certain muscle groups; this is especially manifested in an uncomfortable work posture (27; S. I. Gorshkov, N. A. Kokhanova, O. M. Mal'tseva, 1970; N. A. Kokhanova, A. A. Abdikulov, 1978; Yelizarova, V. V., 1979). In seated work, static tension is experienced mainly by the neck, pectoral and back muscle groups. Stooped shoulders, traumatic radiculitis, spondylosis and other problems may arise in response to extended work in a forced posture (48, 87, etc.). Static muscle tension disturbs normal circulation in the muscles, causes stagnation of blood, deforms the locomotor-bearing apparatus and so on. Extensive work while standing can lead to varicose veins, flat feet and so on.

In many cases a workplace permitting work in a sitting-standing posture may be more sensible. Under these conditions the worker can voluntarily change his posture, as a result of which the loads on different muscle groups are redistributed, and circulation is improved in those portions of the body in which it had been inadequate owing to static tension of muscles helping to maintain the needed posture. Changes in posture introduce a certain amount of diversity in the performance of monotonous work.

In order that work can be done in a comfortable, correct posture, anthropometric data must be accounted for when planning production equipment and workplaces; it should be kept in mind in this case that these data differ for the populations of different countries, and they may even differ for people of the same nationality but residing in different regions of a country.

The limits of workplace zones have been established on the basis of anthropometric data and research on the laws of the locomotor system's work. Different authors divide work zones into several zones--from two to seven, giving different names to them. But all authors agree on the main zones--the optimum zone and the reachable zone. Work within the limits of these zones ensures an optimum work posture--that is, a free and relaxed posture, one in which the torso is not tilted to the side. The worker's body stays vertical in this case, or tilted forward slightly, up to 10-15°.

It should be noted, however, that lengthy work within the reachable zone involving frequent arm movements is tiring, because this raises the tension of muscles in the pectoral girdle and the shoulder and increases the energy expenditures. Moreover movements made by outstretched hands are not distinguished by high precision and speed. Work movements in which the limb is maximally flexed or extended are energetically and neurologically unprofitable because when a limb is moved to one of its limiting positions the lever arm of certain muscles increases, as a result of which these muscles must exert greater force to surmount the resistance of antagonist muscles. In this connection there must be an optimum, most comfortable zone in each workplace, within which work may be performed throughout the entire shift without significant tensing of muscles (M. I. Vinogradov, 1969).

Because incompatibility of the parameters of a workplace to anthropometric data manifests itself in the body's physiological reactions, which often indicate stressing of functions and development of fatigue, the basic workplace parameters must have a physiological basis. After they are afforded the proper physiological grounds, they may be introduced into practice confidently.

The physiological grounds of some work zone parameters may be determined through investigation of workplace models.

Laboratory research has been conducted using specially developed experimental testing units permitting simulation of a workplace intended for a sitting or a standing posture (V. V. Yelezarova, N. A. Kokhanova, E. F. Shardakova, 1978).

Testing units with horizontal work zones were located at a height optimum for easy work while sitting (750 mm) or standing (1100 mm). The workplace for seated work was supplied with a chair having an adjustable seat and back and a footrest. The work zone was simulated in the vertical plane by means of a collapsible experimental testing unit (38).

The experimental testing units were divided into three zones, within which the work movements were planned depending on the precision of the work being done, the frequency with which production operations were repeated, the sizes of the applied forces, the importance of the controls employed and so on.

The efficiency of the movements performed and of the locations of controls in the horizontal plane were determined by the time it took for the hand to reach simulated controls located in different sectors of the zones. In their initial position the hands of the subjects were at the edge of the work surface, 7-8 cm apart.

Because controls are sometimes switched by the worker in production conditions without visual monitoring, the precision of hand movements made without visual participation was studied depending on the location of controls. This research was conducted using the procedure suggested by Kekcheyev and Pozdnova (cited in (60)).

In a study of the efficiency with which controls were located in the vertical plane, the subject responded to an arbitrary signal by raising his hand as fast as possible from its initial position to a control located at a particular height. The biopotentials of muscles taking part in the hand movements were recorded in this case.

It was established from simulation of the zones of seated work in the horizontal plane that the right and left hands reached controls located within zones I and II, and especially within zone I, the fastest (Figure 30A,B,C). When hands were moved from their initial position to controls located in zone III the time required to complete the assignment increased significantly in relation to all sectors within that zone. This time increased to the greatest extent when the control was located beyond the zero line (point 6). When the hands are moved in this direction, the subject turns his body to a certain extent in the same direction. In this case the

the movement time was 234.5 ± 6.7 msec for the right hand and 245.5 ± 4.5 msec for the left. Calculation of the average speed of hand movement showed that as the control is moved farther away from the margin of the work surface, the speed of the movement rises.

Hand movements within zone I were the most precise. They were least precise when the target points were located in zone III, especially if they were behind the zero line. In this case the right hand missed by an average of 27.9 ± 1.1 mm, while for the left hand the figure was 32.4 ± 1.3 mm. The amount the hands missed the target points in zones I and II differed significantly from the errors recorded for points in zone III ($p < 0.01$). It may be surmised from these data that movements of the right hand (for persons with a dominant right hand) are more precise and faster than movements made with the left hand.

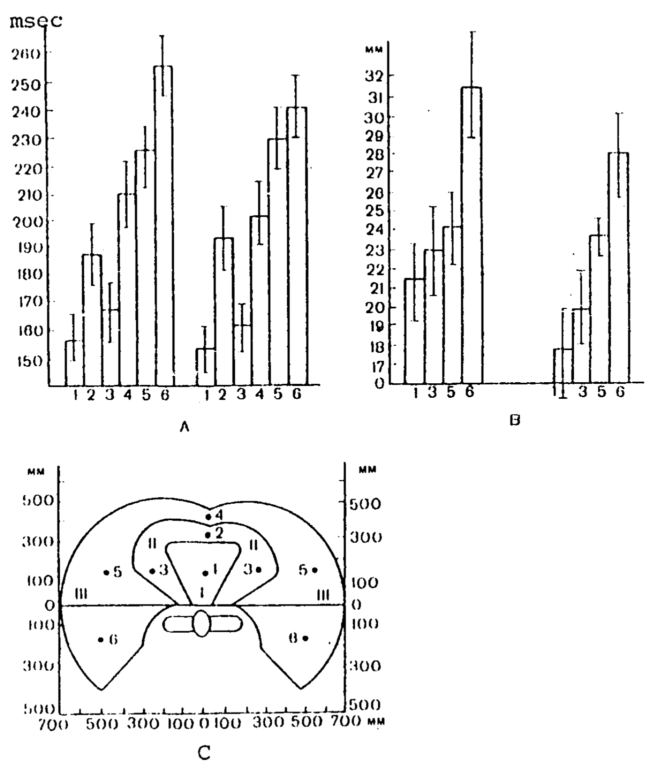


Figure 30. Time of Hand Movement From Initial Position to Simulated Controls Located in Different Areas of the Work Zone in the Horizontal Plane (A); Precision of Hand Movements--Amount by Which Target Points Located in Different Sectors of the Work Zone in the Horizontal Plane are Missed (B); Control Location Zones (C)

The limits of these zones increase somewhat when work is performed in "standing" position--150-200 mm in front and 100-150 mm in depth.

Electromyographic research conducted with the purpose of arriving at the physiological grounds for zones of standing work in the vertical plane showed that the lowest bio-electric activity is observed in hand muscles when the hand is moved from its initial position to a control located from 900 to 1100-1200 mm above the floor (zone I) (Figure 31). When the height of the controls is reduced to 600-750 mm above the floor and when the worker must bend down to operate a control, the amplitude of muscle biopotentials rises. It also rises when the hand must be moved higher than 1200 mm, and especially significantly at heights beginning with 1400-1500 mm (zone III). When the hands are moved to controls located at a height of 1800 mm the biopotential amplitude reaches its peak.

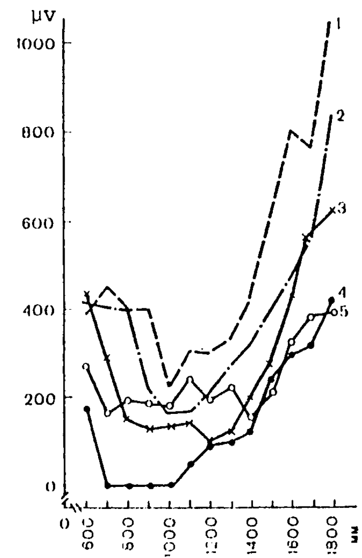


Figure 31. Change in Amplitude of the Biopotentials (μv) of Different Muscles During Movement of Hands Toward Controls Located at Different Heights (mm) From the Floor: 1--pectoral; 2--interior deltoid; 3--medial deltoid; 4--upper trapezius; 5--lower trapezius

Thus zone I (figures 32,33) is the most convenient--that is, optimal--in both the horizontal and the vertical plane. The most precise and very frequent moves may be performed and the most important and very frequently utilized controls may be located within this zone. Sufficiently precise and frequent movement may be performed and important and frequently used controls may be located in zone II (easily reachable zone). Less precise and less frequent movements can be performed within zone III (reachable zone), because owing to the greater amplitude of movements, more time is required to perform them, and if made frequently, such movements become disadvantageous from an energy standpoint. The less important and the rarely employed controls may be located in zone III. Arm movements behind the zero line requiring turning of the torso should be the rarest.

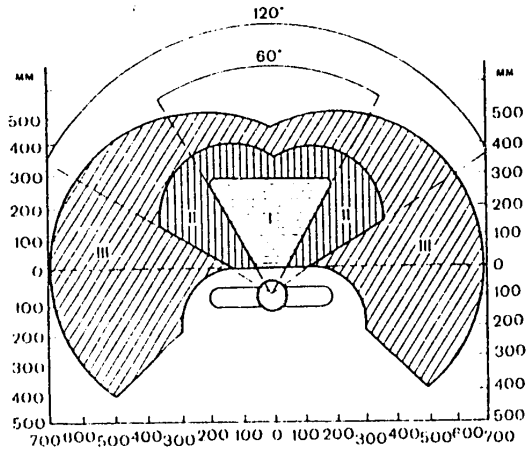


Figure 32. Zones of Control Location in the Horizontal Plane: See text for explanation

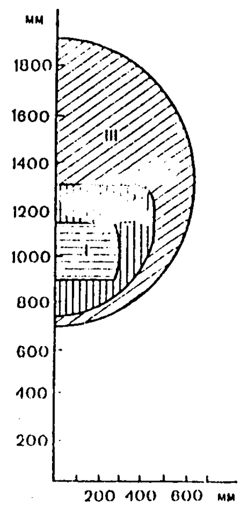


Figure 33. Zones of Control Location in the Vertical Plane: See text for explanation

One important workplace parameter that influences formation of the work posture is the height of the work surface--the vertical distance from the floor to the horizontal plane (real or imaginary) at which the principal work movements are performed. If the work surface is lower, the worker must bend over considerably, and when it is higher he must rise on the balls of his feet and stretch his arms upward to do his work. In both cases the work posture is uncomfortable, the arm movements are in fficient, the body's energy expenditures increase, and the field of view is inadequate. All of this reduces the body's performance, and consequently decreases the effectiveness of the work. The latter is shown graphically in Figure 34, which demonstrates change in the work posture and labor productivity of masons depending on change in laying height--that is, the height of the work surface.

The height of the work surface is determined from the nature of the work being done, its heaviness and its precision. Figure 35 shows the height of the work surface at which the principal work movements of two forms of standing work are performed (900 and 1000 mm). In both cases the main work movements are performed within the optimum zone. For work requiring significant forces, the height of the work surface may be somewhat lower (700-800 mm), while jobs of higher precision require a somewhat higher work surface (1200-1300 mm).

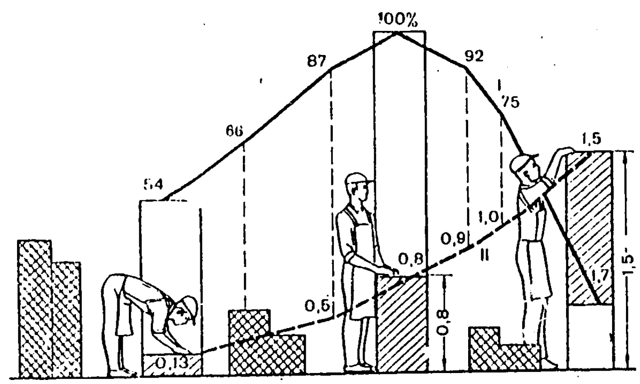


Figure 34. Change in Mason's Labor Productivity Depending on Laying Height: I--labor productivity; II--laying height

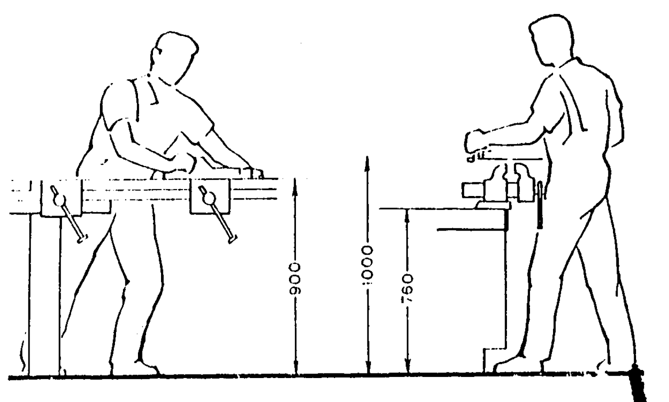


Figure 35. Height of Work Surface for Two Types of Jobs

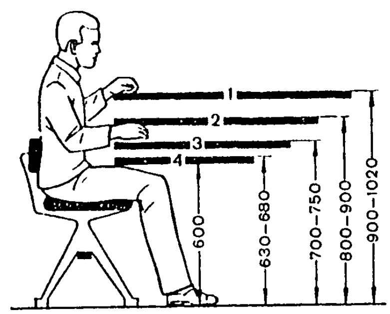


Figure 36. Recommended Heights for Work Surface Depending on Job Type and Precision: 1--very precise and delicate operations; 2--precise work with machines; 3--office work; 4--typing

The workplace would be most comfortable when each worker using it could change its parameters to correspond with his own anthropometric data. In most cases, however, it is still impossible to adjust the height of the work surface. The individual can adapt a workplace with a constant work surface height by adjusting the height of the foot support in standing work and the height of the seat and foot support in sitting work. In these cases the height of the work surface is selected for persons of average height.

The most precise and delicate work (assembly of very small parts, engraving etc.) is usually done sitting down. Such work usually requires visual concentration, and therefore it is often done with the help of optical attachments. In these cases the height at which the main manual work operations are performed must be greater than that for other types of work--900-1020 mm (Figure 36). Because the forearms are raised above the horizontal and the elbow angle is less than 90° in such work, the muscles of the arms and pectoral girdle remain under static tension for a long period of time. To reduce this undesirable factor we install movable arm rests that may be tilted to different degrees in relation to the horizontal plane.

The height of the work surface for precision jobs (assembly of small parts, some machine tool operations and so on) may be 800-900 mm. Arm rests are also installed when necessary in these cases. The optimum range of work surface heights for manual production operations not requiring visual concentration is 70-750 mm above the floor. The desk surface is set at this height for various clerical jobs.

The height of the work surface may be decreased to 630-680 mm for typing and for the use of other keyboard equipment requiring a large number of finger movements. This reduces the static tension of muscles supporting the forearms, since the latter are lowered downward somewhat during work (the elbow angle is greater than 90°).

When organizing a workplace for "seated" work, care should be taken to see that machine parts or structures do not protrude forward and hang above the head within its limits. The height of overhead structures must be not less than 2000 mm. This excludes the danger of bumping the head against such structures when the worker rises.

Leg space must be foreseen to ensure the most convenient and closest approach to the table, machine tool or machine, and to ensure work in a normal posture. Foot space is important in standing work. The room allowed for the feet must be not less than 150 mm in depth, 150 mm in height and 530 mm in breadth. To allow normal conditions for seated work, the leg space must be greater so that not only the feet but also the knees would fit comfortably.

If production equipment does not provide the leg space, the body must be positioned away from the work zone. The worker is forced to bend over and to stretch his arms forward, causing his center of gravity to shift frontward. A forced, uncomfortable work posture is created, maintenance of which requires higher muscle static tension. An efficient workplace for seated work must afford leg space that is not less than 650 mm in depth and 500 mm in breadth. If it is impossible to build in a recess of the required depth throughout all of its height, its depth may be reduced to 450 mm near the knees, increasing it to 650 mm at a point 320 mm above the floor. The height of the leg space must be such that the legs of the seated individual would not touch the lower surface of the table--not less than 600 mm. Many authors believe 700 mm to be the most favorable leg space height.

The design of the chair--its overall dimensions, the shape and tilt of the seat, its height adjustment and so on--has great significance to correct organization of a workplace for seated work with an optimum posture. Research by Moykin et al. (55) showed that owing to unsensible work chair design (insufficient seat surface, absence of a back, too hard a seat), sewing machine operators experienced static tension in muscles of the upper part of the body and waist due to considerable inclination of the head and body.

Depending on their purpose, work chairs may vary in appearance and in the shape of the seat, back and arm rests. However, the seat height of all work chairs should be adjustable. The seat dimensions must be within 380-420 mm in depth and 400-420 mm in breadth. Its forward edge must be rounded downward so that it would not put pressure on the lower part of the thighs.

Despite the fact that very much research has been performed on the work chair, especially abroad, opinions on seat shape are still not unanimous. Some authors recommend tilting the seat 3-5° from front to back (84,88), while others suggest the same angle but prefer the seat tilted forward (K. F. Schlegel, 1956; A. S. Mandel, 1975). Zolina (34) suggests a flat seat. A number of authors feel that the seat must be tilted in back and in front--that it must have a posterior and an anterior taper. The posterior taper is required for support of the sacrum while the anterior taper keeps the body from slipping off (74,79 etc.). Strokina and Plyushkene (63), who studied the bioelectric activity of muscles responsible for maintaining the "seated" posture in relation to different angular sitting parameters, showed that the least back muscle tension is observed when the angle of the anterior taper is 4° and that of the posterior taper is 10-12°. When the posterior angle is 10° the position of the spinal column and pelvis is close to natural, and the body's weight is distributed more uniformly. Work chairs with such seats are furnished to machine operators (GOST 21889-76).

Considering the intricate anatomical and physiological mutual relationships existing in the cervical and lumbar divisions of the vertebral column and muscle groups in different work postures, the design of a work seat must account for the nature of the work, it must be fitted comfortably to the body, and it must allow for voluntary change in posture. Experimental research on seat shape in relation to particular types of work, conducted by Kryukova (44), showed that a work seat with a slight backward tilt is best for workers using keyboard devices and for workers in occupations calling for a similarly organized workplace. A flat, horizontally situated seat is the most comfortable for assembly and installation jobs, for clerical work and for other types of labor at a table requiring little physical effort.

The back is an important part of the work chair. Its presence is found to be especially necessary when the forearms have no support such as the work surface of a machine tool, a table and so on (working with typewriters, table model keyboard computers, card punchers and so on). The significance of the back of a work chair was demonstrated by I. S. Lundervold (1951), whose research established that the bioelectric activity of the trapezius and latissimus muscles of the back is significantly higher in seated work on a backless chair than in work with the back supported. The shape and structure of the back may vary. Thus the back of a chair proposed by B. Akerblom (1948) has two supports: one at waist height (a spinal curvature) and another displaced further to the rear in the vicinity of the scapulas. The lumbar curvature of the back is called "Akerblom's line."

The height of the chair back must be adjustable so that each person could make the back compatible with his anatomical features. In the opinion of most authors it must have an adjustment range of 100-250 mm, and its tilt angle must be adjustable within 3-15°. The height of the back varies from 100 to 150 mm, and its width varies from 275 to 400 mm. The seat and back of a work chair must be semisoft.

In cases where the arms of a worker performing production operations must remain suspended for a long period of time, such that they experience static tension, the design of the work chair should foresee arm rests; however, the latter should not get in the way of the work. Making arm rests semisoft is recommended. So that they would be comfortable, their width must be not less than 50 mm, their length should be not less than 200 mm, their height should be adjustable within 70-200 mm, and the space between them should be 400-500 mm.

Foot rests are important in seated work, especially for short people. They allow the worker to choose a position of the legs at which their muscles are relaxed; otherwise when the leg muscles of a seated person are tensed, conditions favoring congestion of blood in the lower limbs and in the pelvic region are created, leading to rapid tiring. A foot rest must be not less than 300 mm wide and 400 mm deep. The height of its front edge should be adjustable within 260-350 mm, and its tilt should be adjustable within 15-30°. In order that the worker's feet would not slip off, the upper surface of the foot rest is grooved, and a rim 10 mm high is built up on the edge facing the worker.

A support is absolutely necessary with a sitting-standing workplace (Figure 37).

In this case the height of the work surface of the table, machine tool and so on must be the same as for standing work, and it must correspond to the nature and heaviness of the work. The seat of the chair is usually made somewhat smaller than that of a chair of normal fit. The adjustable foot rest is built higher. In some cases a foot rest may be substituted by a leg support taking the form of a footboard. The upper part of the footboard is raised 400 mm above the floor, and its height is adjustable within ±100 mm.

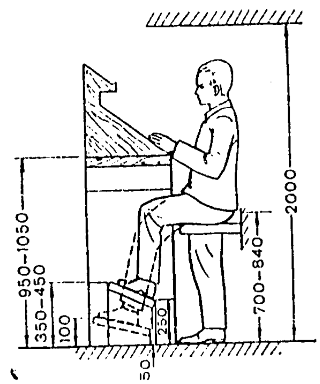


Figure 37. "Sitting-Standing" Work Posture

Special significance is attached to workplace organization in the control cabs of machine units (motor vehicles, excavators, tractors, hoisting cranes and so on). The driver's alertness and performance depend on how comfortable his work posture is, how freely he can use the levers, pedals and other controls and how well his comforts are seen to for long hours of work in the cab.

The choice of optimum seat dimensions and location of levers, pedals and instruments of the cab workplace is based on the anthropometric data for a person of average height. Visibility from inside the cab has great significance to the normal work of the driver. An important requirement imposed on seat design is to create a supporting structure which would not cause discomfort and which would realiably support the driver in the course of his control operations. In order that the driver would not bump his head against the roof when the cab bounces vertically, a clearance of 50-100 mm should be provided above the head.

Research by Kozlov (36) showed that if these dimension requirements are not met for a tractor cab, a tractor driver wishing to avoid bumping his head against the roof is compelled to work bent over. Moreover because of inadequate cab visibility the tractor driver must often work in an asymmetrical position, with his body tilted to the right. This means that the body's center of gravity is shifted to the right of the supporting surface, and the static tension of the muscles consequently increases. The undesirable features of such a posture include tilting of the body toward the horizontal plane, the side tilt of the pectoral girdle and pelvis and arisal of compensatory scoliosis of the vertebral column in the cervical and lumbar divisions. Electromyographic studies have shown that the bioelectric activity of muscles keeping a tractor driver's body in an asymmetrical position is seven to eight times greater than that recorded with the body in the normal posture recommended by the author.

As he controls the vehicle, the driver imparts certain forces to the levers and pedals. Locating levers at a height between the shoulder and elbow is recommended in cabin design, since this permits the operator to exert the greatest force. The size and shapes of levers must correspond to the dimensions and gripping features of the hand. When locating levers relative to the floor, preference should be given to vertical levers over horizontal ones. Being a support to the hand, a vertically oriented lever supports its weight. Depending on the particular features of the cab workplace, the height of levers may be 750-1060 mm above the floor.

Consideration of the Functional Characteristics of Analyzers

As he works, the individual constantly receives information on changes in the object of labor as a result of its processing, on the work of the machine, on change in the production process and the environment, and so on. The effectiveness of labor depends to a significant extent on how correctly and quickly the operator perceives incoming information. This in turn depends on the functional state of analyzers taking part in perception and processing of signaling information.

The olfactory and especially the gustatory analyzers are useful to work relatively rarely. The visual, auditory, cutaneous and proprioceptive analyzers have important significance to work.

When planning equipment, organizing a workplace and designing the control and information display resources, we must correctly choose the main and auxiliary indication systems and determine the loads experienced by different analyzers in correspondence with this. If the functional state of the analyzers is to be kept at the optimum level their physiological characteristics must be considered, and an attempt should be made to create favorable conditions for their operation.

For the visual analyzer to work effectively, general illumination and illumination at the workplaces must comply with the established public health norms, light fixtures must be located correctly in relation to the work zone, and the object of labor and the indication resources must be located optimally.

When organizing local lighting, care should be taken to see that the light source does not hinder the workers. For this purpose the light fixture must be located not less than 35-40° above the horizontal line of sight (Figure 38). In cases where the light source is located below this limit it hinders the operator and reduces the effectiveness of vision by 40-50 percent; when the angle is reduced to 23° rapid tiring can be noted, and visual effectiveness decreases by 50-70 percent. Location of the light fixture at a 10° angle elicits painful sensations in the eyes. Constant uniform illumination of the workplace is recommended. When lighting is nonuniform, shifting of the gaze from a lighter area to a darker one or vice versa is accompanied by adaptation of the visual analyzer. The time required for adaptation may have an effect on the rate of signal detection.

Also unfavorable is location of the light source in such a way that light reflected from the work surface strikes the eyes. Following intense blinding by light, it may take up to 10 minutes for vision to become normal again. Disturbance of visual monitoring during work has an influence on the speed and quality of the work done.

The functional characteristics of the visual analyzer must also be considered when locating controls on production equipment, laying out various control consoles and distributing displays on them. Optimum working conditions may be achieved if the console design accounts for the spatial-temporal structure of the visual analyzer.

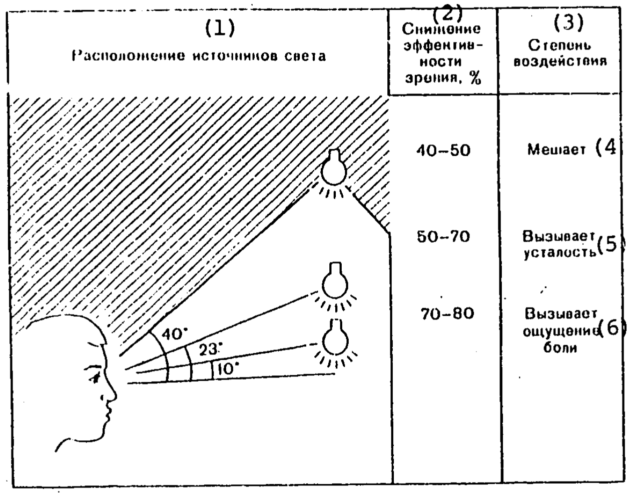


Figure 38. Effect of the Location of a Light Source on Visual Effectiveness

Key:

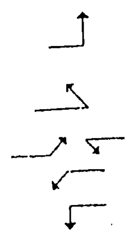
1. Location of light sources
2. Decrease in visual effectiveness, %
3. Degree of influence
4. Hinders
5. Elicits tiring
6. Elicits painful sensation

Eye sensitivity is known to decrease from the center to the periphery. The point toward which the gaze of an observer is concentrated is called the center of the visual field; all other points are in the periphery. As the distance from the center to the periphery of the visual field increases, the outlines of perceived objects and their colors become less distinct. As a light stimulus moves farther from the center of the visual field toward the periphery, the latent period of the oculomotor reaction increases (22). The extent of the change depends on the qualifications and functional state of the operator. This should be considered when organizing the workplace, when installing various indication resources and when quick and precise motor reactions to visual signals are required. However, it should be kept in mind that peripheral vision is more sensitive to slowly moving light stimuli. When the individual perceives the arisal of a dynamic light signal, he turns his gaze toward it in order to evaluate it and make a decision. This is especially important to transport drivers.

When the individual observes signals and objects, his eyes constantly make micromovements in the form of discrete jumps. The angle within which such a jump occurs is called the angle of instantaneous vision, and the zone delimited by this angle is called the zone of instantaneous vision. According to the data of different authors the angle of instantaneous vision is within 5-18°. Visual perception is restricted in time within these limits.

As the eyes perform micromovements, microsignals arise as the initial stage in formation of the image of an object. The duration of discrete eye jumps is in the hundredths of a second, and the interval between them is 0.2-0.5 seconds. The more complex the object being examined, the more complex is the route taken by the eyes. A study of a number of simple routes of identical length but differing in direction and angles (30°, 90°, 150°) showed that the time to travel the route depends on its direction and the size of the angle (Table 15). The position of the angle in space has significance (52).

Table 15. Average Total Traveling Time



Route	Traveling Time, msec
	765
	845
	890
	925
	965

Eye micromovements are associated with functions such as search, fixing the eyes in a position for optimum information reception, identification, measurement and control (31; B. F. Lomov, 1966). The optimum or effective zone for these functions is one delimited by a 30° angle in the horizontal and vertical planes (15° to either side, and upward and downward from the normal line of vision) (Figure 39). Within this zone perception is sufficiently clear and the shape and color of an object are readily distinguished; this is why locating the main and emergency indicators and the main controls of production equipment within this zone is recommended.

The total time T is the sum of several components:

$$T = t_1 + t_2 + t_3 + t_4,$$

where t_1--latent period of the first jump; t_2--time of movement along the first side of the angle; t_3--length of pause with the eye fixed on the apex of the angle; t_4--time of movement along the second side of the angle.

Less-important information displays may be located in the zone adjacent to the optimum zone, while rarely employed components can be located in a zone with even wider limits. In the latter case the operator must turn his head and eyes to observe information displays.

The three-dimensional structure of the working perceptual field may include several concrete fields to which the operator successively shifts his gaze. As an example a typist may deal with three fields in her work: the material being transcribed, the keyboard and the typewritten text. Owing to development of an occupational habit, the three-dimensional structure of the field of observation may become simpler: An experienced typist rarely looks at the keyboard. In cases where an individual must service several machine tools or automatic devices with information displays located significant distances apart, the operator must move from one field to another.

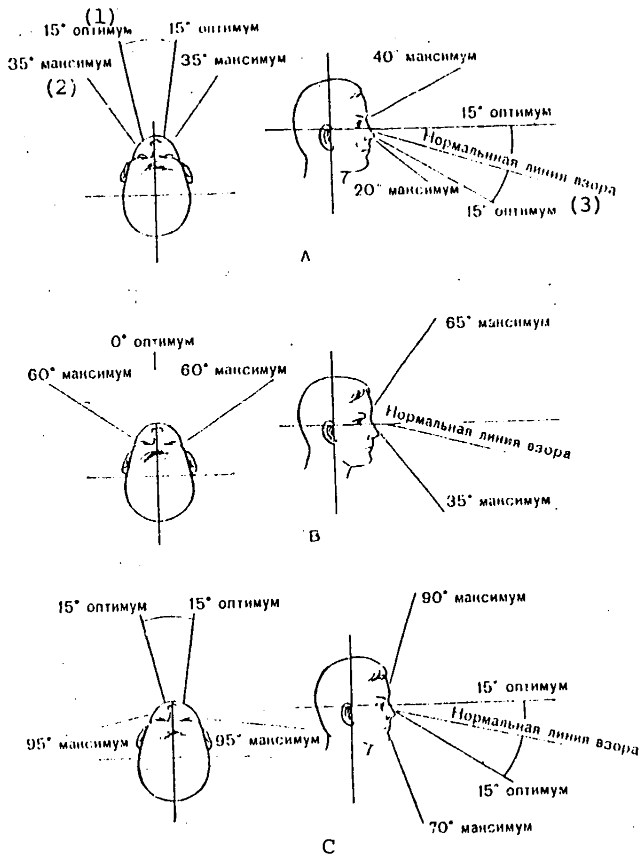


Figure 39. Visibility Zones in the Vertical and Horizontal Planes (32): A--when turning only the eye; B--when turning the head; C--when turning the head and eye

Key:
1. Optimum
2. Maximum
3. Normal line of vision

A designer considering the location of controls on equipment and of information displays on control consoles should consider that horizontal eye movements are faster than vertical ones, and that horizontal proportions and dimensions are estimated more accurately than vertical ones; the latter are usually overestimated. Leftward and upward movements of the eyes are faster than in the reverse direction. Straight lines are easier to follow than curved ones, and smooth changes in line direction are perceived more easily than abrupt changes. Application of the vector-electro-oculographic method to research on perception of elementary rhythmical compositions (circles, stripes and so on) on a plane showed that perception of rhythmically repeating series occurs in a direction from larger to smaller elements, from darker to lighter elements and from elements with smaller intervals between them to those with larger intervals (45).

The rate and effectiveness of information perception and processing rise significantly when we introduce an auxiliary indicator to which the worker must turn special attention. Figure 40 shows that the time for determining the location of the pointer on a scale bearing an auxiliary indicator is significantly shorter than without it. It is often suitable to delineate the "normal" zone of a scale with a colored stripe, since in this case an operator checking a reading need only perceive and evaluate the mutual arrangement of the pointer and the indicator mark. The effectiveness of an indicator mark's perception rises if it differs from other marks not only in color but also in shape (32; W. Schultetus, 1974).

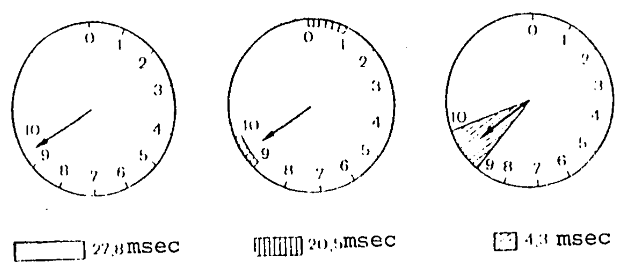


Figure 40. Display Reading Time in the Presence of an Auxiliary Indicator and Without It

In cases where the operator's visual analyzer is overloaded with information or where visual perception is difficult owing to unfavorable conditions (poor illumination, intense vibration and so on) it would be suitable to switch part of the information to the auditory analyzer.

Acoustic signals are used to transmit simple information of short length, for example if additional information must be transmitted or if the operator must be warned that a signal is forthcoming.

A tonal acoustic signal coding system must account for the fact that man can perceive 16-25 gradations of tonal signals differing in pitch or loudness. The absolute thresholds of the auditory analyzer depend significantly on the frequency of the acoustic signal and the differential thresholds in relation to intensity and frequency--on the initial values of these characteristics, that is. In the acoustic range, the differential intensity threshold is about a tenth of the initial signal intensity, while the differential frequency threshold is 3-5 Hz at an intensity not less than 10 db. Signal duration has a significant influence on the thresholds. The minimum duration of a sound which would permit evaluation of its quality is 20-50 msec. At lower duration, a sound is perceived as a click.

The auditory analyzer deserves special attention in the planning of emergency warning resources. Acoustic information is perceived faster than visual information by man. Man's sensomotor reaction to an acoustic signal is 20-30 msec faster than to a light signal. This difference stems from the difference in the rate at which incoming information is processed in the analyzers, owing to their morphophysiological characteristics. Perception of a stimulus in the visual analyzer is associated mainly with photochemical reactions within its peripheral unit. This reaction proceeds somewhat more slowly than does information processing in the peripheral unit of the auditory analyzer. To perceive a danger signal through his visual analyzer, man must keep the location at which a signal may possibly arise within sight. The need for focusing attention in this way is avoided when we plan in acoustic warning signal transmission. In perception of an acoustic signal, the location of its source in relation to the operator does not have a significant influence.

The auditory analyzer is able to receive a large quantity of information in the form of spoken messages. This form of transmission acquires special significance when the work involves the need for fast two-way information exchange. The main characteristics of acoustic oscillations are intensity, frequency and shape, which are reflected in auditory sensations as loudness, pitch and tone quality. The range of acoustic oscillation frequencies perceived by the human ear is 16-20,000 Hz. Frequencies corresponding to the spectrum of human speech--200-3500 Hz--have special significance within this range.

A designer working on apparatus to transmit spoken messages must know the basic characteristic of speech, which is a combination of sounds varying in intensity and frequency. The intensity of uttered vowels and consonants differs: Vowels are typified by greater intensity. Between the loudest vowel and the quietest consonant there is a 30-40 db range of sound intensity.

Production conditions are sometimes such that spoken messages are transmitted in the presence of noise. In cases of not very loud noise, speech is usually comprehensible if its intensity is 6 db above that of the noise. It should be kept in mind in this case that words of two syllables are recognized 30 percent better than words of one syllable, while words of three syllables are recognized 50 percent better. The maximum rate of message transmission is 250 words per minute. However, in order that it could be perceived and understood correctly it must be transmitted at an optimum rate--120 words per minute; in this case the length of a sentence must not exceed 10-11 words. With longer sentences the effectiveness of reception decreases owing to the limited volume of the working memory (G. K. Sereda et al., 1976).

It should be noted, however, that use of the auditory analyzer to perceive information is limited by the difficulty of receiving and analyzing information coming in simultaneously from more than one source of warning signals.

The cutaneous analyzer is important to man's work. Using tactile receptors, the individual can receive information on the location of an object in space, on its form, surface, the quality of the material from which it is made and so on.

Vibration arises rather often during work with production equipment. Man also senses vibration by means of tactile receptors. In this connection vibration at the workplace can serve (within permissible limits) as a source of information by which to monitor the work of transportation resources, mechanisms, machine tools and so on.

The absolute sensitivity of tactile receptors to mechanical stimuli is defined as the minimum pressure necessary for arisal of a sensation. Thus the absolute sensitivity of the lip is 1-50 mg/mm^2; that of skin on the back and abdomen is 10 gm/mm^2, the discrimination threshold being 7 percent of the initial pressure. Receptor elements subjected to mechanical stimulation produced by vibration are most sensitive to vibration frequencies in the 100-300 Hz range (G. K. Sereda et al., 1976).

Efforts are now being made to find broader uses of tactile receptors to transmit information to the operator. Vibrators mounted on particular areas of the skin are used for mechanical warning signal transmission. Attempts are being made to use painful and electrocutaneous stimuli as signals indicating an emergency situation.

Nevertheless, information transmitted by tactile receptors is not distinguished by diversity owing to their morphophysiological characteristics. In terms of the quantity of information perceived, the cutaneous (tactile) analyzer is significantly inferior to the visual and auditory analyzers. We can achieve not more than 10 gradations of vibrotactile or electrocutaneous signals by changing their frequency. Difficulties in using tactile receptors to transmit information on the course of a production process are also associated with the individual's rather swift adaptation to them, and the difficulty of storing signals in the memory.

The proprioceptive analyzer, which aids in control of motor activity, has important significance. Information coming from muscle and joint receptors permits the individual to determine exactly the location of body parts, changes in posture and movements, determine the weight of objects, compare the force required to lift objects of different weight and so on. Proprioceptors take part in automatic regulation of posture and movements, operating on the basis of feedback between actuating organs and the central nervous system. Acquisition of information on the results of an action helps the operator to master an equipment control system faster and to adapt to different characteristics of the controls.

The functional characteristics of the proprioceptive analyzer should be considered when designing and locating controls that could be used effectively not only with visual control but also without it.

This entire discussion permits the conclusion that when different information resources and different methods of information presentation are used with a consideration for the functional characteristics of human analyzers, the incoming production information can be perceived more quickly and precisely, and it can be analyzed and the appropriate decision can be made more correctly.

The Power and Speed Characteristics of the Human Body, and Their Consideration in the Design of Equipment Controls

The working individual performs various work movements and applies forces of varying magnitude. Work movements made by the hands may be associated with the need for switching equipment controls or with lifting and moving the object of labor, and so on. The effectiveness of work depends significantly on the quality of work movements, on their efficiency. In cases where movements are efficient and economical, a production assignment can be fulfilled with lower energy expenditure. It is precisely in economical and efficient use of work movements that the principal reserves and possibilities of decreasing fatigue and improving the performance of the individual and increasing labor productivity lie.

While working, a laborer may often spontaneously select a variant of work actions which is often not optimal. This variant becomes habitual for him, and it persists in this inefficient form for a long time. In order to prevent such cases, the structure and possibilities of the human motor apparatus must be kept in mind when planning the labor process, and the workplace should be organized with a consideration for these characteristics.

First of all we need to comply with the principle of economy of movement, which in its simplest form entails elimination of extra movements. In this regard correct organization of the workplace acquires important significance: The main production operations should be performed within the limits of the optimum zone, while operations of secondary importance should be performed in the reachable zone. Frequent bending and shifting of the body can also be precluded by sensibly distributing office supplies. Constancy of location of tools, attachments, intermediate products and so on at the workplace has great significance. When work movements become habitual, they become automatic, and they require less expenditure of attention, time and energy for their performance.

Extra movements can be eliminated by making a work process more efficient. This can be done by excluding procedures that would not be missed. Thus exclusion of yarn cutting in a sole stitching operation in footwear production reduced the number of movements in the operation by four. In this case the number of movements per shift decreased by 2640, and the distance traveled by the hands decreased by almost 1 km (8). At the same time a differentiated approach should be taken to eliminating extra movements, as M. I. Vinogradov notes. In cases where production operations are too simple, such as for example when working on certain conveyors, the physiological significance of each movement must be evaluated. In these cases exclusion of a movement as being technically unjustified may result in even greater simplification of the stereotype and reduction of its dynamics, and consequently the uniformity and monotony of the work would increase even more.

Economy of motion may also be achieved by efficient use of active and passive forces. This means that a work movement must be controlled through sensible utilization of the force of gravity and inertia. Thus if a work movement involves the lowering of an arm, muscle force would be needed at first to surmount the arm's inertia; the rest of the movement can be made on the basis of inertia, without exertion of muscle force. In order that the movement would be economical, a high speed should be generated at first (fast accumulation of kinetic energy occurs), so that the force of inertia could be capitalized upon subsequently.

Depending on the nature of the work assignment, different elements of the human motor apparatus may participate in the work movement. Thus certain jobs may basically require only the use of fingers and a hand; a hand and forearm; a hand, forearm and shoulder, with and without the body's participation. In each case the working kinematic chain must correspond to the link-by-link distribution of muscle masses brought into action. An attempt should be made to make the greatest possible use of small muscles of the arms (hands, forearms) for light work, and rarer use should be made of large muscles (of the pectoral girdle, waist and torso). The greater the participation of joints in a motor act, the more energy is expended on it.

There are now fewer and fewer jobs associated with large forces, requiring the participation of large proximal muscles of the limbs and torso. But even in light work, for example assembly of small parts and work with keyboard equipment, besides the small distal muscles of the hands, large muscles of the back and shoulders participate, mainly by carrying the static load of maintaining the work posture. Where possible, static tension is reduced by introducing supporting elements for nonmoving limb segments, and the most laborious elements of the work are mechanized.

When planning a work process, it is important to know that the strength and speed of contraction of different muscles are not the same. Table 16 shows the strengths of different muscle groups of the man's and woman's arms, recorded from a large number of persons by Uflyand (64). As we can see from this table, the strength of the right arm is greater than that of the left; in this case the degree to which this asymmetry is expressed by different muscle groups varies--4-8 percent of muscle strength.

Table 16. Strength of Different Muscle Groups (kg) (64)

Indicator	Men	Women
Strength of the hand (squeezing a dynamometer)		
Right	38.6	22.2
Left	36.2	20.4
Strength of biceps		
Right	27.9	13.6
Left	26.8	13.0
Wrist flexure		
Right	27.9	21.7
Left	26.6	20.7
Wrist extension		
Right	23.4	18.5
Left	21.8	16.7
Thumb strength		
Right	11.9	9.0
Left	10.9	8.3
Standing strength (muscles straightening the bent torso)	123.1	71.0

Muscle strength changes with age. The greatest muscle strength is observed at 20-29 years (at 25 years on the average); then it decreases gradually, and beginning at age 50 it decreases more abruptly. The muscle strength of people in the 60-69 year age group is 20-45 percent lower than that of persons in the 20-29 year group.

Muscle strength changes owing to prolonged work in a particular specialty. An occupation's influence on the strength of different muscle groups may vary. Thus Uflyand, who studied the strength of different muscle groups among representatives of different occupations, revealed that arm strength is highest among persons doing heavy physical labor and glass blowers, wrist flexing and extending strength is highest among workers of a brewery, and thumb strength is greatest among painters. Figure 41 shows the hand muscle strengths of persons in different occupations from 30 to 49 years old.

The force generated by the moving arm depends on its position. When the individual is standing, the greatest force is generated at shoulder level, while when he is sitting, it is highest at the elbow level.

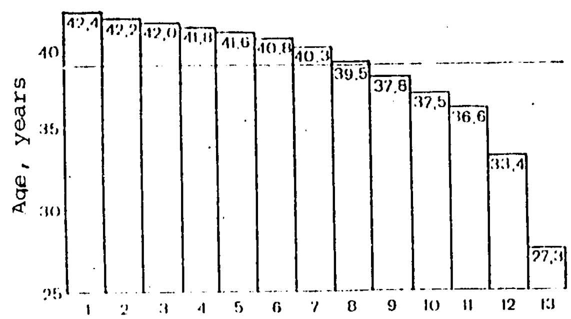


Figure 41. Hand Muscle Strength (kg) for Persons in Different Occupations 30-49 Years Old (64): 1--persons in heavy physical labor; 2--longshoremen; 3--glass blowers; 4--bakers; 5--fitters; 6--brewers; 7--boiler makers; 8--type founders; 9--painters; 10--persons doing metal work; 11--typesetters; 12--typists; 13--ropemakers; horizontal line--average for all subjects--39 kg

Table 17 shows the maximum force generated by the right and left arm in different directions of movement (toward the body, away from the body, up, down, left, right) in sitting position (85). However, it would not be permissible to demand maximum effort in work; maximum effort should be applied for short periods of time only--several seconds. At the same time, if we know the maximum possible effort that can be generated, we can standardize permissible and optimum values more correctly. Permissible effort values must be associated with rarely used controls. Optimum effort may be applied by the worker frequently while servicing production equipment. However, the question as to what the mutual relationship is between the size of the effort applied and the frequency of its application is still not fully resolved yet. A certain amount of attention is being devoted to this question today. Applied efforts have been standardized for some controls. Compliance with these standards when planning and designing production equipment should promote optimization of human labor (GOST's 21752-76, 21753-76).

The speed of arm movements depends on their direction and trajectory as well as on which muscles take part in the given movement. Thus flexors of the arms contract faster than extensors, but the latter can generate greater force. Consequently movements toward the body and from right to left are performed faster (by the right arm) than movements away from the body and from left to right, but they lose out in the amount of force generated. Hence it is clear that it would be best to control speed levers with arm flexors and power levers with extensors.

Table 17. Arm Strength in Sitting Position While Performing Movements in Different Directions (85)

(1) Положение руки	(2) Величина силы движения, кгс			
	(3) Тяга		(4) Толкание	
	(5) левая рука	(6) правая рука	(5) левая рука	(6) правая рука
	(7) К себе		(8) От себя	
180°	52,6	54,4	57,2	62,6
150°	50,8	55,3	50,3	55,9
120°	42,6	47,2	44,9	46,7
90°	36,3	39,2	37,6	39,0
60°	29,0	28,6	36,3	41,7
	(9) Вверх		(10) Вниз	
180°	18,6	19,5	15,9	18,6
150°	23,6	25,4	18,6	21,3
120°	24,5	27,2	23,1	26,3
90°	23,6	25,4	22,2	24,0
60°	20,0	22,2	20,9	23,1
	(11) Слева	(12) Справа	(13) Влево	(14) Вправо
180°	19,5	22,7	13,6	15,4
150°	21,3	24,5	13,2	15,0
120°	20,4	24,0	13,6	15,4
90°	21,8	22,7	15,0	16,8
60°	22,7	23,6	14,5	19,0

Key:
1. Arm position
2. Force of motion, kg
3. Pulling
4. Pushing
5. Left arm
6. Right arm
7. Toward the body
8. Away from the body
9. Upward
10. Downward
11. From the left
12. From the right
13. To the left
14. To the right

Horizontal arm movements are faster and less tiring than vertical movements; when frequent movements are required, the arm should not be raised above the shoulder.

The trajectory of motion has important significance. Movements having long trajectories are more tiring; therefore we should try to keep trajectories short. Linear movements, however, which are the shortest, are undesirable. Owing to the anatomical characteristics of the joints between arm segments, which have spherical, block and elliptical form, movements on curved trajectories are more natural and efficient. Straight trajectories require additional muscle tension to hold the joint still.

Arm movements must be rhythmical, simple and habitual, and they must be made within the limits of the work zone and the visual field. Transitions from one type of movement to another must be as smooth and comfortable as possible. Smoothly rounded movements are faster than linear movements having abrupt changes in direction. Curved movements and circular movements are preferable to movements following broken trajectories. Skilled workers performing plastering, gluing and other jobs use curved movements predominantly. Performance of movements along a smooth trajectory is more efficient; it is more justified from an anatomical and physiological standpoint, and the work proceeds more rhythmically.

In addition to the conditions for economy of motion cited above, we should keep in mind that it may also be achieved by complying with rules such as simultaneous motion, symmetrical and rhythmical motion, and so on. This means that both arms must begin and end their work simultaneously. When working with one arm, it would be a good idea to keep the other arm "busy."

The simplest and fastest movements are symmetrical movements by both arms in the same plane but in opposite directions (Figure 42A,B). It is harder to make movements in the same direction (Figure 42C, D), and still more difficult to make successive movements, with one arm performing a movement that has just been performed by the other. The hardest are movements made in different planes (Figure 41E). The greatest coordination is observed to be required in machine tool operations in which rotating movements by one arm are combined with linear movement by the other in a different plane (Figure 42F).

Were we to analyze movements performed during manipulation of controls in different planes, we would note that clockwise rotary movement corresponds to straight movement to the right, upward and forward (in relation to the operator), while counterclockwise rotary movement corresponds to straight movement to the left, downward and back (Figure 42G,H).

Rhythmical performance of work movements is recommended, but the rhythm must be free, or at least to some degree induced, for example by music played in the production shop. Owing to development of fatigue, the movement rhythm of the workers may change in the course of the shift.

An effort should be made to create working conditions in which the habits of performing the principal work movements "automatically," without psychological loads, would develop the fastest.

Comparative analysis of the work of laborers at different skill levels has revealed that the work of a highly skilled worker is distinguished by high organization. He prepares his workplace before starting work. Owing to careful study and analysis of the work process, such a worker does not make unproductive movements. He works rhythmically, performing his work movements along short, smooth trajectories. An efficiency expert wishing to make a work process more efficient does so in integration with improvements in the production operation and assurance of full utilization of the equipment's capacity (53; S. A. Kosilov, 1965).

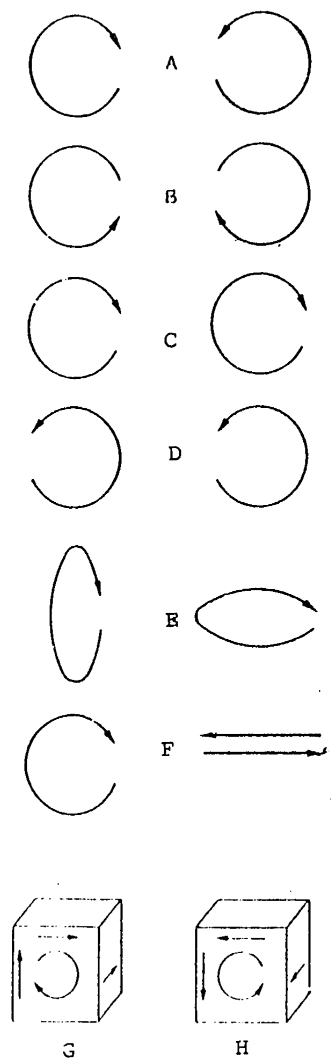


Figure 42. Nature of Different Work Movements: See text for explanation.

Owing to correct choice of work movements and improvement of the efficiency of the labor process, worker tiring decreases significantly and labor productivity rises by 5-25 percent (66).

The strength and speed characteristics of the human motor apparatus must be considered when designing equipment controls. Creation of manual controls with regard to sensible efforts and directions of movements and with regard to the ease with which handles and various levers can be gripped would promote economy of effort of the worker and faster performance of controlling actions.

When designing and locating the various controls, the designer must try to see that their manipulation would be simple, that they could be easily reached and seen by operators, and that their location is coordinated with that of indicators. All controls and information displays must be located in a way that would exclude mutual interference when performing control operations and accidental operation; they must have enough resistance to reduce the possibility of their accidental movement. The work of controls must be maximally reliable even when unexpected directions of movement occur.

When designing controls, rules such as optimum applied effort and minimum free play must be observed. Appropriately limiting the rotating speed of hand wheels and cranks is recommended as a way to prevent the danger of injury to the operator during automatic and accelerated operation.

Various ways to code controls are used to facilitate control and to decrease mistakes and the time required to find the needed control.

Manual controls, which permit precise and fast adjustment, are used most frequently to control production equipment. The greatest precision and speed are noted with appropriately designed manually operated controls; use of large forces for a long period of time is not permitted. Controls requiring application of considerable force are placed into motion with two hands. When a control wheel is controlled with two hands, the force required to put it into rotation must be doubled. A similar increase in effort is required for movement of a straight lever or handle, located near the body along its midline, with both hands (toward and away from the body). If a lever is located far away from the body, the force advantage gained by working with two hands is insignificant.

Manual controls intended for different purposes can be distinguished in relation to shape, size and structure. Pushbuttons or tumbler switches are recommended for a start-stop operation. Buttons are advantageous because they can be pressed quickly, with little effort by the fingers. There can be three basic types of buttons in relation to form of action: 1) press to turn on, release to turn off; 2) press once to turn on, press a second time to turn off; 3) press to turn on and lock.

The optimum location for buttons when working in seated position is at the level of the elbow when the arm is bent 90° at the elbow and the forearm is horizontal. It is easier and faster to press a button that protrudes somewhat from the surface of the table. In this case the angle between the hand and the table surface must be 30-45°. The optimum tilt angle of the keyboard of a push button console is 15°.

Rectangular buttons with rounded corners or a rounded upper edge are the most convenient when frequent use is required (Figure 43A). Rarely used buttons may be round. The button surface must be somewhat concave or roughened, so that the finger would not slip off when the button is pressed. The button should click to indicate to the operator that he has effectively operated the button. Buttons may be color-coded to facilitate discrimination. The optimum diameter of a button actuated by a fingertip is 13 mm. If a button is intended for emergency use or if it is intended to be pressed by the thumb or the palm, its diameter should be increased to 18-19 mm. The button should move 3-6 mm when pressed.

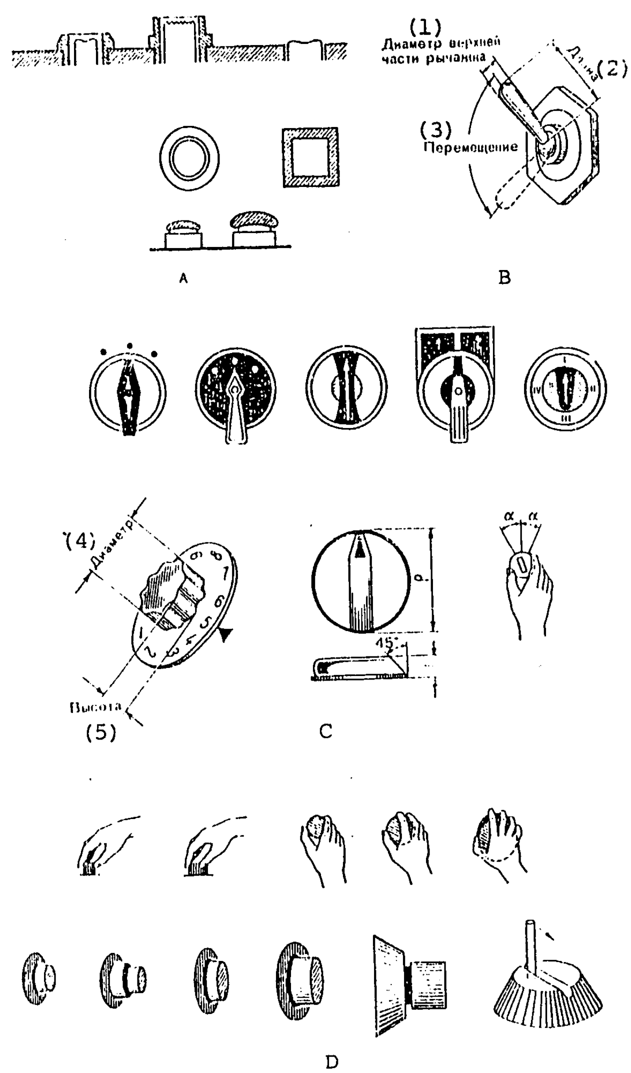


Figure 43. Manual Controls: A--buttons; B--toggle switch; C--rotating switches; D--rotating knobs

Key:
1. Diameter of upper part of arm
2. Length
3. Movement
4. Diameter
5. Height

In addition to buttons, keys that may be located in rows are often installed in control consoles and on other work surfaces to permit fast switching.

Permissible and optimum forces must be used as guidelines when planning various types of manual controls. In cases where controls are used over and over again during work, the permissible forces may be decreased. Thus rarely used buttons can have a depressing force within 0.60-1.20 kg, while that of frequently employed buttons is 0.14-0.16 kg.

Toggle switches are often used to turn components on and off and to switch them. It would also be sensible to use toggle switches whenever controls must be located close together: Their spacing can be 25 mm. The position of a toggle switch can be recognized both visually and by touch. Toggle switches usually have two positions, and sometimes three. The amount of resistance depends on the size of the toggle switch arm. Recommended forces are 0.3-0.5 kg for arms up to 30 mm long, and 1 kg for arms 50-100 mm long (Figure 42B).

The functions of a switch may also be performed by rotating switches, which are especially suitable when there are a large number of discrete working positions. Rotating switches have from 3 to 24 working positions. Such switches must be located in such a way as to ensure enough room for free manipulation by the hand.

Switch diameter may vary from 25 to 75 mm, and sometimes up to 102 mm; the applied force can vary from 0.3 to 1 kg (Figure 43C).

Rotating knobs that do not require considerable effort or precise movements are used for precise and rough adjustment of mechanisms. These controls can be easily coded by color and shape. A collapsible arm can be secured to a knob so that it could be rotated faster. The knob diameter is varied within a broad range depending on how many fingers must grasp the knob to rotate it (Figure 43D). The permissible forces in this case are 0.5-3 kg.

Operations in which switching is performed by a forward-backward or lateral motion make use of levers and handles. Levers usually require application of force to move particular equipment mechanisms. Levers with spherical heads having a 30-75 mm diameter or with pear-shaped handles are recommended (Figure 44A). Permissible forces applied to levers during their control must not exceed 15 kg for one hand and 25 kg for two hands (assuming back-and-forth movement). When levers are to be used often, actuating forces are reduced to 2-4 kg. The amplitude of a lever's movement must correspond with the reachable zone of the operator's arm; in this case the arc traveled by the lever must not exceed 90°.

Hand wheels are used for equipment control and for accurate adjustment (Figure 44B). It would be desirable to impart a rippled surface to the rim of a hand wheel; the rim diameter must not exceed 25 mm. If a hand wheel is brought into motion by wrist action, the applied force may be up to 1 kg; if the arm up to the elbow or the entire arm takes part in the work movement, the force can be up to 4 kg. If a hand wheel must be turned at high speed, it would be suitable to locate it in such a way that its axis of rotation would be at a 60-90° angle in relation to the operator. Hand wheels requiring application of considerable torque would best be located perpendicular to the operator.

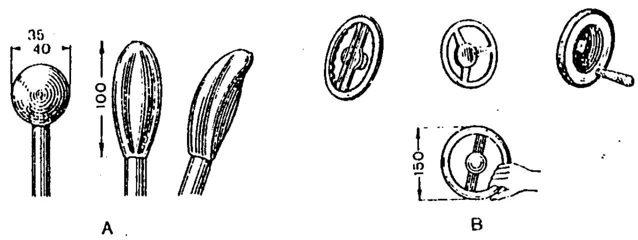


Figure 44. Manual Controls: A--levers; B--hand wheels

As with other controls, hand wheels that are used especially often should be located within the optimum work zone.

In addition to manual controls, foot-operated controls can be made to place various mechanisms and production equipment into operation and to make adjustments. Pedals are the principal form of foot controls. They are used when sizeable muscle forces are required (more than 9-13 kg), to reduce the load on the arms, and to achieve economy of control time when a large number of controls must be manipulated and when the work does not require considerable adjustment precision.

A designer planning pedals and locating them at the workplace must consider that the force generated by the leg depends on its position. A seated operator exerts the greatest force when his leg is extended forward with an obtuse angle at the knee. If the seated individual is able to force his body against the back of his seat, he can significantly increase the pushing force of his leg. The force developed decreases as the angle at the knee decreases. Maximum force can be developed when the pedal is located not more than 100 mm from the midline of the operator's body. The pressure the leg can apply decreases as we move farther from the midline (Figure 45).

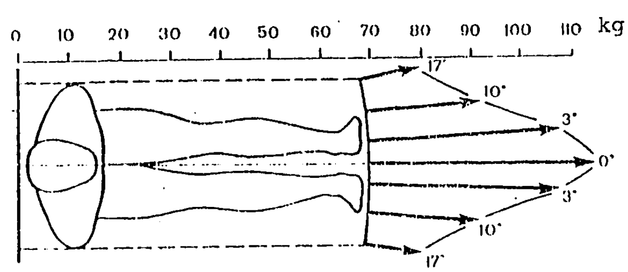


Figure 45. Change in Pushing Force of Leg With Growth in Distance From Midline

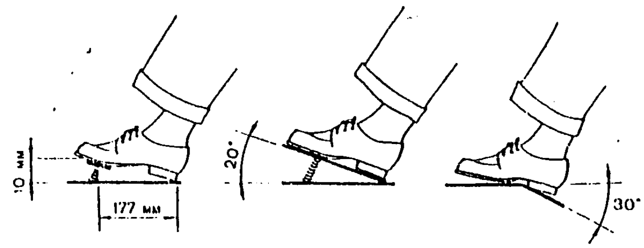


Figure 46. Basic Types of Pedals

Pedals would best be located symmetrically. Each leg can control not more than two pedals. A pedal may be depressed by the entire foot, by its middle part or by the toes (Figure 46).

The design of a foot pedal should account for the fact that the ankle should not be turned more than 30° in working position. The optimum amplitude of ankle motions is within 10-20° above the horizontal and 20-30° below; in this case the pedal stroke must not exceed 130-150 mm in seated work and 300 mm in standing work.

Avoiding pedal control in standing position is recommended, since in this case the weight of the body would have to be shifted to one leg as the pedal is being pressed. Maintenance of a stable position would require additional muscle effort. As a result the muscles of the legs and body tire more quickly.

If pedal control in standing position cannot be avoided, the height of the pedal above the floor must not exceed 150 mm. At the end of its stroke, the pedal should be level with the floor.

The optimum force applied to a pedal by a standing operator is 10-15 kg. This force is decreased to 8-3 kg during seated work depending on which part of the foot is used to depress the pedal.

The pedal width must correspond to the width of the sole (not less than 90 mm). The minimum length of a pedal used for short periods of time is 60-75 mm. If a pedal must be kept depressed for a long period of time, its length may be 280-300 mm. The shape of the pedal may be square, rectangular or oval; in all cases the pedal surface must make good contact with the sole. Imparting a rippled surface to its surface is recommended. A special rim is made on its surface to keep the foot from slipping off of the pedal when considerable force is exerted.

Some Characteristics of Ergonomic Requirements on the Design of Equipment to be Operated by Women

Physiological requirements on the design of production equipment are governed by the characterstics of its use, and they include the comfortableness of the work posture, the amount of effort exerted, the speed and trajectory of work movements their number per unit time and the characteristics of information interactions.

These requirments are basically common to male and female operators, but ones such as comfortableness of the work posture, the proportions of workplace dimensions and forces necessary to perform production operations depend on the anatomical and physiological features peculiar to the sex of the operator. Thus the proportions of workplace dimensions would differ for men and women depending on anthropomorphic indicators.

According to anthropological data the height of men and women in the USSR differs by 11.1 cm (men (M)--167.8, women (W)--156.7), body length with an upstretched arm differs by 15.7 cm (M--213.8, W--198.1), the length of the arm stretched to the side differs by 6.2 cm (M--72.3, W--66.1), the length of the arm stretched forward differs by 5.7 cm (M--74.3, W--68.6), leg length differs by 6.6 cm (M--90.1, W--83.5), eye level differs by 10.1 cm (M--155.9, W--145.8) and so on. These rather noticeable differences would also mean pronounced differences in the proportions of the dimensions of a workplace intended for work while standing.

The same sort of differences between men and women apply to seated work. Body length differs by 9.8 cm (M--130.9, W--121.1), eye level above the seat differs by 4.4 cm (M--76.9, W--72.5) and so on, which has a bearing on the organization of a workplace for seated work and on determination of the reachable zone and the clearances required.

According to S. I. Gorshkov's data, cited below, the brakes on wool spinning machines used to stop the spindle with the purpose of mending broken strands of yarn are located just 4-6 cm above the knee. However, this slight excess is quite enough to make it necessary for spinners to raise their knee to this height in order to depress the brake and mend a broken yarn strand while standing uncomfortably on one leg.

Because the spindle tie rod on spinning machines used to process cotton yarn is located 5-10 cm below hand level, the standing spinner must incline her body to an uncomfortable position 60° below the horizontal in order to mend broken strands. In cotton production this operation is performed 2000-2500 times in a shift, which means a significant static load on muscles of the spinner's torso.

The amount of effort exerted by particular muscle groups during use of equipment must be determined on the basis of dynamometric data. However, these are different for men and women as well.

The gripping force of the right hand differs for men and women by 16.4 kg (M--38.6, W--22.2), the strength of the right biceps differs by 14.3 (M--27.9, W--13.6), the flexing force of the right hand differs by 6.2 kg (M--27.9, W--21.7), the flexing force of the right thumb differs by 2.9 kg (M--11.9, W--9.0), standing force differs by 62.1 kg (M--123.1, W--71.0) and so on. Differences in the one-time weight lifting limit and in the amount of weight that can be handled within a shift are associated with these differences in the strength of the muscle groups of men and women. Thus while the recommended one-time lifting limit for men is 20-30 kg and the shift norm for weight handling at the level of the work surface is 10-15 tons and at the floor level is 4-6 tons, the figures for women working under the same conditions are not more than 40 percent of the figures for men.

These and other differences between men and women must be accounted for when designing production equipment, since otherwise the physiological requirements on the proportions of workplace dimensions and on work effort would not be met, resulting in uncomfortable work postures and in the need for women to exert effort that is too tiring. Some other characteristics of the ergonomic requirements on the design of production equipment intended for use by women must also be considered.

These differences between the male and female body are being considered now in the planning of the "Volzhanka" tractor intended to be driven by women. The dimensions of this tractor's cab and the workplace, the locations of the levers and the amount of force required to operate them, and the zones of visibility are being planned with a consideration for the indicated characteristics of the female body. These differences should obviously be considered in the design of many other forms of equipment as well.

Number of Operations Required in the Use of Production Equipment

The number of operations performed during the use of production equipment is the most important ergonomic characteristic of the mutual relationships between man and equipment, and it is an indicator of the heaviness and intensity of the work. However, there are no substantiated standards applicable to this area today. Nor has an approach been found to determination of the principle upon which standardization of this ergonomic indicator should be based. The "Unified Requirements on Scientific Organization of Labor" compiled by the Scientific Research Institute of Labor (1967) contain recommendations indicating that the maximum physiologically grounded repetition of operations is 180 per hour. In this case an operation frequency from 181 to 300 times per hour is said to be high, a frequency from 301 to 600 is said to be above average, and a frequency more than 600 times per hour is called very high. An excessive frequency of identical production operations makes the work monotonous, consequently leading to development of inhibition in the central nervous system, a decrease in the speed of work movements and a drop in labor productivity. But these recommendations are in very considerable conflict with facts concerning the number of operations performed during the use of different types of production equipment. Inspection of firmly established facts concerning the number of operations performed in different production conditions would show that winders perform 500 operations per hour while servicing winding machines, while cotton yarn spinners may perform up to 300 or more operations per hour if the frequency of strand breaking is high. Bulldozer and excavator drivers also perform an enormous quantity of operations. The operator of an excavator supplied with a large number of control levers moves the latter 12-16 times in a single work cycle (20 seconds), and more than 15,000 times in a shift, which is equivalent to about 2000 operations in 1 hour of work. According to V. N. Kozlov's data the number of work movements made by a tractor operator in 1 hour of shift time while plowing exceeds the recommendations of the Scientific Research Institute of Labor.

Despite the fact that production operations proceed in a strict sequence, the control consoles of a number of machines are still designed in such a way that each operation must be controlled separately by the operator. This is so even at modern automated enterprises, for example in automatic tube rolling mills. In such shops, an operator working the control console of an annual furnace moves levers on the control console 12 times to feed one billet into a piercing mill. This succession of movements is repeated with each of 250 billets processed in 1 hour of work. Thus the operator of such a console makes a total of up to 3000 repetitive lever movements in 1 hour while simultaneously performing other production operations that will be discussed in greater detail below. Operators working on wine bottling lines perform up to 2000-3000 repetitive manual operations per hour. In addition to these instances in which the actual number of performed operations greatly exceeds the recommended standards based on the "Unified Requirements on Scientific Organization of Labor," cases are known in which it is very difficult to perform much fewer operations than the number suggested by these recommendations. Thus weavers mend warp strands 50-60 times per hour with great difficulty, even though not more than 35-40 mendings per hour was adopted as the maximum permissible quantity back in 1961 at the First Conference on the Problems of Labor Hygiene and Physiology in Textile Industry, held in Ivanovo.

Table 18 [missing from this translation] provides a detailed summary of the actual numbers of repetitive operations associated with different types of production equipment. This great diversity of the actual numbers of operations performed in the course of different production procedures and their great deviation in both directions from the standards contained in the "Unified Requirements on Scientific Organization of Labor" indicate the need for studying this question and, in particular, the need for examining the physiological ideas about rate and rhythm typical of an individual performing repetitive actions, about the significance of the rate at which different neural reflex reactions proceed, about the differences in the complexity and time of different operations encountered in production and about the significance of these data to determining the permissible number of such operations during the use of production equipment.

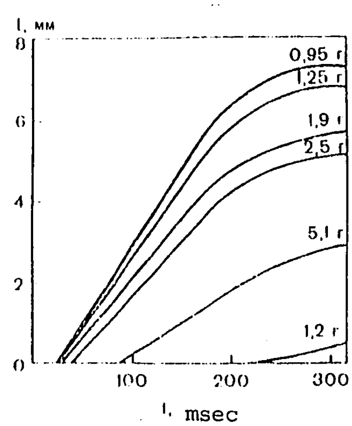


Figure 47. Isotonic Contraction of the Sartorius Muscle in Response to Different Loads: Numbers above the curves indicate the load, $I_0 = 27$ mm, temperature 0°. Ordinate--contraction magnitude; abscissa--time after application of a single stimulus (28)

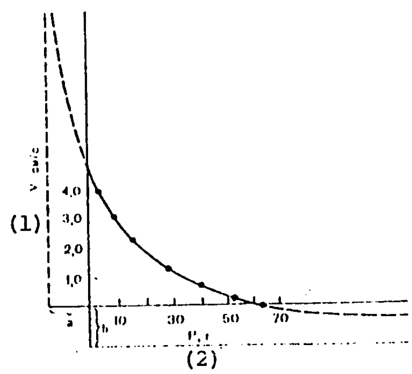


Figure 48. Rate of Tetanic Contraction as a Function of Load (Given Equal Initial Length): Ordinate--contraction rate; abscissa--load (Hill, 1938)

Key:
1. cm/sec
2. gm

Let us first of all examine some of the physiological characteristics of muscle activity. We should turn our attention first of all to the fact that the duration of a single muscle contraction is not constant, depending instead primarily on the size of the load imposed on the muscle (28). We can see from Figure 47 that the larger the load, the greater is the time between the moment a single stimulus is applied and the beginning of its isotonic contraction. An increase in the time between the moment of stimulus application and the beginning of muscle contraction does not mean an increase in the latent period of the muscle's contraction; instead, it indicates that the time required to develop tension in the muscle necessary to surmount the load applied to the muscle is added to the latent period. The greater the load, the greater is the time, as Figure 47 shows. While at a load of 0.95 gm this time is about 20 msec, at a load of 12 gm it reaches as much as 200 msec--that is, a magnitude which becomes a significant factor in the rate of muscle contraction. The rate of muscle contraction also depends on the size of the load. As we can see from Figure 48 the rate of tetanic muscle contraction decreases as the load increases. According to calculations made by A. V. Hill (1938) this dependence is hyperbolic and is described by the formula

$$(P+a)(V+b)=b(P_0+a)=const,$$

where V--rate of muscle contraction in the presence of load P; P_0--weight at the limit of the muscle's lifting strength; a and b--asymptotes toward which the branches of the hyperbola tend.

For the case of the curve shown in Figure 48: $a=14.35$ gm (357 gm/cm^2); $b=1.03$ cm/sec (0.27 I_0/sec); $P_0=66$ gm (here, I_0 is the resting length of the muscle).

Physiological data concerning the optimum rhythm of muscle contraction and its dependence on the size of the load are of considerable interest. As we know, this question was studied by Hill. It is presented here as amplified by A. A. Ukhtomskiy (1954).

Studying initial heat formation, Hill came across the fact that under otherwise equal experimental conditions the most widely diverse muscles, when stimulated by different methods, exhibit constancy in the relationship between heat formation and the product of the length of muscle fibers and their maximum tension. This constancy is expressed by the formula

$$H = bL\tau,$$

where H--heat formation; b--proportionality factor; L--length of muscle fibers; τ--maximum isometric tension.

Because the product $L\tau$ represent a muscle's energy of elastic tension--that is, its mechanical potential, we can write the equation

$$W_0 = b_1 Lt,$$

where b_1--proportionality factor; W_0--muscle's mechanical potential.

Comparing these two expressions, we may conclude that heat formation in a muscle serves as a measure of not its dynamic work but rather its elastic tension--that is, its mechanical potential. The energy of a muscle's dynamic work (isotonic contraction), meanwhile, is a certain fraction of its mechanical potential. Theoretically, all 100 percent of a muscle's mechanical potential may be used for mechanical work. For practical purposes, however, part of the mechanical potential is expended to surmount the muscle's internal friction--that is, its toughness. This fraction is transformed into heat, and the greater the toughness in the muscle and the faster the muscle contracts, the greater is this fraction. One can be persuaded by passive stretching of a muscle that the smaller t_1 is--that is, the shorter the muscle deformation time, the greater is the amount of heat liberated due to stretching. Representing the coefficient of muscle toughness by k, we get the following expression for the actual amount of energy realized in the form of mechanical work:

$$W = W_0 - \frac{k}{t}.$$

Hence we can see that W approaches W_0 as: first, muscle deformation decreases--that is, as opposition to contraction rises; second, as the toughness coefficient, which is actually capable of decreasing in response to massage and exercising of muscles, decreases; third, as the rate of muscle contraction decreases.

We can derive a large amount of new information from these data on the physiological properties of muscles, and mainly on muscle efficiency. To calculate this efficiency, we would need to know the total amount of energy released in the muscle in the period of initial heat formation in response to stimulation. This total should consist of: 1) mechanical potential W_0, to which the constant quantity of heat released by the muscle upon release of tension corresponds; 2) the amount of heat required to maintain tension for time t, associated with liberation of lactic acid.

(Khartri) and Hill followed the course of total heat formation depending on time of tension t. It is expressed (Figure 49) as almost linear growth of heat formation in response to growth in t; the higher the muscle temperature, the faster heat formation grows, but no matter what the temperature of the muscle, heat formation begins at the same constant value corresponding to the lowest t. This constant, shown in Figure 49, equals

$$G = \frac{L\tau}{5,5}.$$

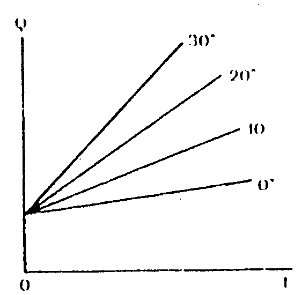


Figure 49. Magnitude of Initial Heat Formation and the Dependence of Heat Formation on Muscle Temperature

Keeping in mind that potential energy developed in a muscle owing to stimulation exhibits an identical dependence on $L\tau$, and namely $W_0 = L\tau/6$, Hill believes it possible to physically interpret the constant point of the ordinate's intersection (see Figure 49) as corresponding to the thermal equivalent of muscle mechanical potential at maximum tension.

As far as the slope of the line representing the dependence of heat formation on growth in time t is concerned (see Figure 49), it clearly implies that for every muscle temperature there is a unique proportion between heat formation associated with accumulation of lactic acid and the time of this accumulation. Let us call this proportion (or in this case the slope of the conditional lines drawn) b. Then the general trend of total initial heat formation would be expressed as a function of stimulation time in the form of a simple equation for a line passing the ordinate at point W_0 and slope b, which is constant for each temperature:

$$G = W_0 + bt.$$

It would not be difficult to determine b from the amount of oxygen consumed during maximum isometric contraction.

Delayed heat formation, which implicates an entirely different chemical process than that of initial heat formation, is approximately equal to the latter in a stretched muscle. Consequently total heat formation in a muscle during stimulation would be:

$$G = 2(W_0 + bt).$$

Then the ratio of realized energy W to total heat formation G would be:

$$\frac{W}{G} = \frac{W_0 - \frac{k}{t}}{2(W_0 + bt)}.$$

Certain conclusions can be made from this expression. Obviously as time t decreases the numerator on the right side decreases, and when $W_0 = k/t$, it becomes zero. On the other hand as t increases the denominator grows, tending toward infinity. This means that there must a maximum productivity for each t--that is, for each rate of work, such that slower work, and faster work even more so, would inevitably cause a decline in productivity. Hill determined the factors for man in special experiments: $W = 11.18$ kg/mm, k (toughness coefficient) $= 2.7$ and $b = 5$. Then for man, W/G takes the form of the equation

$$\frac{W}{G} = \frac{11{,}18 - \frac{2{,}7}{t}}{2(11{,}18 + 5t)}.$$

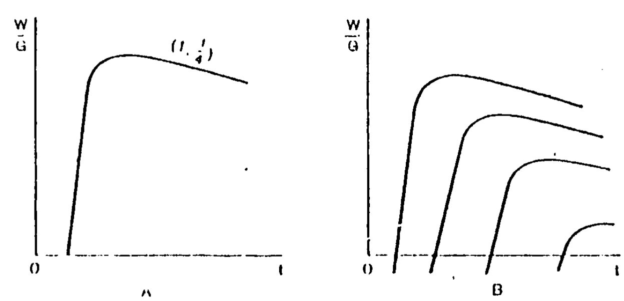


Figure 50. Muscle Efficiency and the Dependence of the Optimum on the Rate of Contraction and the Size of the Muscle Force: See text for explanation

There are two variables in this equation, W/G and t. We plot W/G on the ordinate and t in the form of a curve (Figure 50) having a critical point with coordinates 1,1/4. The branches of the curve drop downward asymmetrically to either side of this point, very steeply in the direction of decreasing values of t (that is, increasing speeds) and gently in the direction of increasing values (that is, decreasing speeds). The coordinates of the critical point (1,1/4) tell us that maximum muscle productivity corresponds to development of an active process within the muscle once per second; optimum productivity, meanwhile, is 1/4, or 25 percent. These calculations, made by Hill, were confirmed by data obtained by Benedict and Cathcart indicating that an individual does the most productive work on a bicycle when he pushes the pedals 60-70 times a minute; maximum productivity, in the sense of mechanical work, has been estimated for man at about 25 percent by former and recent researchers.

Important conclusions can be derived about the role of forces in the work of muscles from the expression for W/G. We know that when maximum force is exerted, the working muscle develops tension in all of its fibers, while at submaximum force only a certain fraction of the fibers contained within the muscles are tensed. Let n be a certain fraction of muscle fibers, the total being 1. Obviously the mechanical potential for n active fibers would be nW_0; let heat formation be $G=2n(W_0+bt)$; let the loss due to muscle toughness remain as k/t; that part of the tension energy utilized in the form of mechanical work would be $W=nW_0-k/t$. Hence productivity would be

$$\frac{W}{G}=\frac{nW_0-\frac{k}{t}}{2n(W_0+bt)}=\frac{nW_0-\frac{nk}{nt}}{2n(W_0+bt)}=\frac{n\left(W_0-\frac{k}{nt}\right)}{2n(W_0+bt)}=$$

$$=\frac{W_0-\frac{k}{nt}}{2(W_0+bt)}.$$

If for this last equation we plot curves (as we did above) for different n, we would get Figure 50--a series of curves with continually decreasing amplitudes and critical points, and displaced more and more in the direction of greater values of t (in the direction of slower work) as n--that is, the force applied--decreases. This means that if lower force is applied in work, the latter is always less productive as well. As the forces applied decrease, the productivity optimum decreases to slower rates of work. As forces increase, the productivity optimum rises to higher rates of work. But even here the most advantageous frequency of active states in a muscle at maximum force is once per second.

Such are the physiological principles behind our ideas about the most optimum conditions of muscle work, at least in terms of muscle processes taken in isolation. But because muscles are only one of the elements of man's complex motor apparatus, there are some unique characteristics in human motor activity, which will be examined below.

The discussion thus far has shown that processes that may influence the rate at which production operations are performed and the frequency of their repetition occur in the muscles themselves. Characteristics of nervous system functions have an even greater influence.

Every work action is an act involving the participation of a reflex arc. Therefore the characteristics of an excitation's propagation through a reflex arc would reveal themselves in the temporal parameters of work-associated actions. The most important functional characteristic of the reflex arc is the existence of a latent period between the moment of arisal of a stimulus and the beginning of the responding motor reaction. The duration of the latent period of motor responses is mainly a factor of the response rate.

According to S. I. Gorshkov's data (1963) the duration of the latent period depends on the analyzer responsible for the given motor reaction, on the composition of neurons participating in the reflex arc and on the properties of the conducting pathways.

The more distally the muscle group which is the target of a response is located, the greater is the latent period of the response, for example to a visual stimulus. In this case the increase in the latent period would correspond to the increase in the length of the motor nerve that transmits the signal to the muscles; this increase would be precisely proportional to the rate of propagation of the excitation along the nerve. Thus the latent time of a response by the leg to a light stimulus is 20-30 msec longer than that for a response by the arm. The difference in size of the latent period is more pronounced in relation to different points of application of the signal stimulus. Thus the latent period of a reaction to a thermal contact stimulus applied to the wrist would be 200-300 msec longer than that for a thermal contact stimulus applied to the shoulder. The difference in latent time of a painful stimulus applied to the wrist and shoulder would be 50-100 msec. In both cases the latent time increases due an increase in the distance the afferent impulse is transmitted from the place of stimulus application to the appropriate centers in the brain. The greatest lengthening of the latent period is observed in a choice reaction, where the subject must determine which stimulus he must react to. In this case the increase in the latent period is 100-300 msec.

In addition, faster responses are also possible. A decrease in the latent period is observed in the response to a stimulus preceded by a warning signal, and to a stimulus that had previously been tracked--for example the moving pointer of an instrument or a light spot, with the reaction beginning when the moving pointer or light spot reaches a certain position. In both cases the response is faster by about 100 msec.

Thus response time can vary within broad limits depending on the analyzer responsible for the response on the length of the sensory and motor pathways, on the nature of the signal, on the need for signal choice, on presence of a warning signal and on some other features of the situation within which the response occurs.

We have been discussing muscular and reflex mechanisms of change in response rate. It should be kept in mind, however, that tiring, arousal or inhibition and presence of external influences may also have a noticeable effect on human responses. This will be discussed specifically in our analysis of concrete occupational situations.

The time of a response also depends on the action within which this response expresses itself and on the portion of the body participating in the response. These data are shown in Table 19.

The trajectories of motor reactions also play a great role in their duration (Table 20).

Table 19. Dependence of the Length of a Response on Its Nature

Nature of Response	Minimum Response Time, msec
Pressing down with the palm	330
Moving the fingers	170
Pressing with the hand	720
Flexing and extending:	
Arms	720
Legs	1,330
Pressing a pedal	720
Turning, bending the body	2,000
Walking (taking a step)	700-1,400

Table 20. Time Spent on Motions Depending on Trajectory Length

Type of Motion	Time Spent, msec
Extending arm, mm	
25	70
50	140
More than 300	210
Placing an object	
Not in a precise spot	360
Forcefully, not in a precise spot	720
With great force	1,800
In a precise spot	550
Forcefully in a precise spot	900
With great force	2,300
Moving an object more than 180°	210
Pressing on an object	720
Compressing an object with the fingers	720
Taking an object that is	
Light and easy to grasp	70
Light but hard to grasp	140
Light but from among other objects (depending on dimensions)	300-800
Wrapping fingers around an object	200
Transferring from one hand to the other	200

Taking apart	
Effortlessly	180
With slight force	360
With significant force	1,100
Pressing	
With the toe	360
With the foot	720
Taking a step sideways without turning	700-1,400
Turning the body	
While sitting	720
With a step to the side	700-1,400
Bending over	1,000
Unbending	1,000
Sitting down	1,400
Standing up	1,800
Taking a step 75-80 cm long	600

Note: The time indicated in all of these examples does not include the latent period of the reaction; only the time spent on the motion itself is considered.

These data can be supplemented by the results of special experiments performed at the ergonomics laboratory of the USSR Academy of Medical Sciences Institute of Labor Hygiene and Occupational Diseases by S. I. Gorshkov, G. I. Barkhash and E. F. Shardakova. The dependence between the duration of movements and the number of joints participating in the movements was studied in these experiments. The experiments are diagrammed in Figure 51. In Figure 51A, the diagram labeled 1 shows the joints of the human arm labeled as follows: *a*--index finger, *b*--hand, *c*--forearm, *d*--upper arm, *e*--torso. This figure also shows the starting position of the arm for determining initial latent time. The latter was determined for a subject responding to a light or sound stimulus by depressing the key of a reflexometer with his index finger with barely noticeable force. Position 2 in Figure 51A shows that in this case the initial position for determining the reaction time was with the index finger raised as high as possible above the surface of the reflexometer's key. In position 3 the entire hand was initially raised as high as possible, in position 4 the entire forearm was raised as high as possible, in position 5 the entire arm as far as the shoulder joint was raised to the maximum, and in position 6 the entire arm was raised at the shoulder joint as high as possible with the entire body tilted back. In all cases the subject had to quickly depress the reflexometer key with his index finger.

In Figure 51B the diagram labeled 1 shows the joints of the human leg, labeled as follows: *a*--big toe, *b*--foot, *c*--lower leg, *d*--thigh, *e*--torso. The initial latent time of the reaction to light and sound was determined in position 1 with the subject depressing the reflexometer key with his big toe with barely noticeable pressure. In position 2 the starting position for determining reaction time was with the big

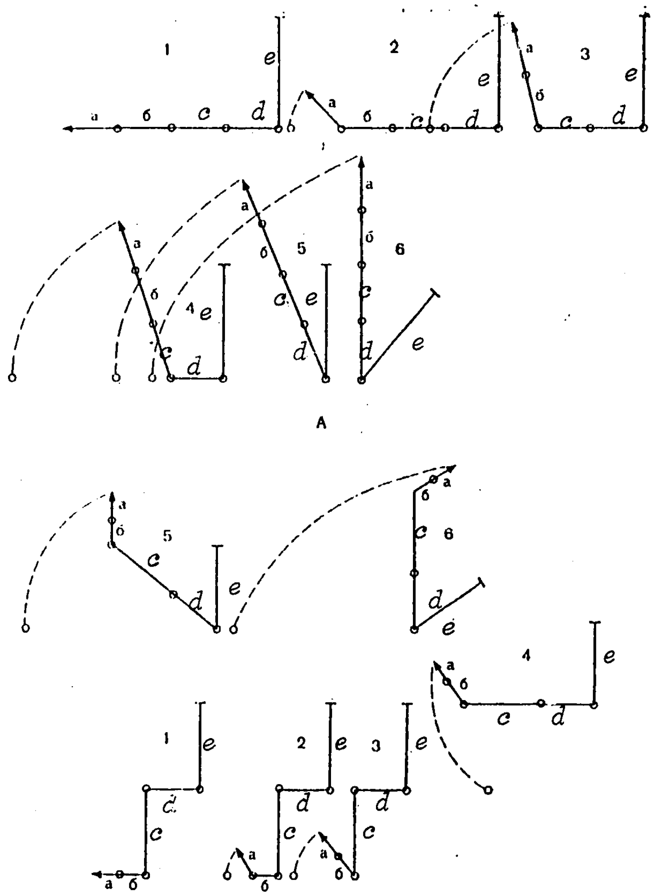


Figure 51. Experiments Conducted to Study the Dependence of Latent Time on Distance Traveled by Joints: See text for explanation of positions 1-6. Broken curves show motion trajectories (A-B)

toe raised as high up as possible above the key, in position 3 the entire foot was raised to the maximum, in position 4 the lower leg was raised as high as possible, in position 5 the thigh was raised to the maximum, and in position 6 the entire leg was raised as high as possible at the hip joint with the torso tilted back. The results are shown in Table 21.

As we can see from these data, the time of the motor reaction increases as the number of joints participating in the movement increases. Thus for example, if the index finger is raised the reaction time to light is raised by 36 msec, the reaction time to sound is raised by 29 msec, and the time of the choice reaction is raised by 29 msec--that is, it takes 29-36 msec to move the raised index finger down

Table 21. Dependence of Motor Reaction Time (msec) on the Nature of the Motor Component

(1) Позиции (см. рис. 51)	(2) Реакции					
	на свет (3)		на звук (4)		выбора (5)	
	M±m	p	M±m	p	M±m	p
(6) Рука						
1.	186±9		168±6		225±6	
2.	222±5	(7) Ср. 1—2 <0,01	197±3	Ср. 1—2 <0,001	254±4	Ср. 1—2 <0,01
3.	239±4	Ср. 2—3 <0,02	217±6	Ср. 2—3 <0,02	275±9	Ср. 2—3 <0,05
4.	479±6	Ср. 3—4 <0,001	434±4	Ср. 3—4 <0,001	506±15	Ср. 3—4 <0,001
(8) Нога						
1.	210±11		185±6		244±6	
2.	266±8	Ср. 1—2 <0,01	250±3	Ср. 1—2 <0,001	298±4	Ср. 1—2 <0,001

Key:
1. Positions (see Figure 51)
2. Reactions
3. To light
4. To sound
5. Choice
6. Arm
7. Avg.
8. Leg

to the reflexometer key. The increase in time of movement of the tip of the index finger to the reflexometer key with the hand raised to the maximum is 53 msec in response to light, 49 msec in response to sound and 50 msec in the choice reaction--that is, it varies within 49-53 msec. The increase in time of movement of the tip of the index finger to the reflexometer key with the forearm raised as high as possible is 293 msec in response to light, 266 msec in response to sound and 281 msec in the choice reaction--that is, it varies within 266-293 msec. If we assume that the finger travels 5 cm when it is raised as high as possible above the reflexometer key, in this case it would take

$$\frac{266\ (293)}{40} = 6\ (7)\ \text{msec}$$

for the finger to travel 1 cm. These data are doubtlessly of great interest to ergonomic evaluation of movements.

The maximum possible frequency of movement of specific joints and body parts depends on the duration of movements (Table 22).

Having analyzed all factors influencing the duration and speed of particular human motor reactions, we can generalize all of these data with the following equation:

$$T_0 = t_r + t_m,$$

where T_0--total duration of the motor act; t_r--reaction latent time; t_m--time of movement itself. Both components may be changed to a certain extent, as was discussed above, and this change represents that reserve which may be used to make movements more efficient.

Table 22. Maximum Possible Movement Frequency

Nature of Movements	Maximum Frequency Per Minute
Applying pressure with the palm	180
Moving the fingers	360
Pressing with the hand	80
Flexing and extending	
The arms	80
The legs	45
Pressing a pedal	80
Turning, bending the body over	30
Walking (depending on length of step)	40-80

It is obvious from this that the standard suggested by the Scientific Research Institute of Labor for the number of permissible repeated operations can be viewed only as roughly tentative. There obviously cannot be just a single standard; there must be several of them depending on the nature of movements used in the given production operation. At the same time it is obvious that creating this standard is one of the pressing tasks of ergonomics.

Characteristics of Informational Interaction During the Use of Production Equipment

As was discussed earlier, informational interaction between an operator and his machine, being a source of production information, consists of the perception, memorization and processing of information, and response formation.

Attention, which can be described as the orientation of consciousness upon a certain circle of phenomena or actions, has great significance to information perception. Attention can be described from a physiological standpoint as arousal of a certain group of centers and inhibition of neighboring ones. In this sense the physiological basis of attention is very close to A. A. Ukhtomskiy's dominant. When a pronounced dominant is present, the stimulus to perceive certain information is so high that attention becomes selective. A sleeping mother who is not awakened by cannonfire wakes instantly to the quiet crying of her sick infant.

Attention is distinguished as voluntary, when it is actively focused on something, and involuntary, when a certain suddenly arising event attracts our attention. The main properties of attention are its stability or is diffuseness. The span of of stable attention may be long, as happens in interesting or easy work, or short when the work is uninteresting or hard. Rosner (86) believes that stabilization is especially important to operations associated with seeking faults in yarn or fabric, or monitoring the apparatus of an electric power plant with a control console. Personnel performing such operations may experience a decrease in their attention, or they may even fall asleep at the workplace. Investigation of the attention of operators watching for signals to appear revealed that the degree to which attention is concentrated, as determined from the number of missed--that is, unnoticed--signals, clearly decreases with the 15th minute of observation and reaches a minimum at about the 45th minute, after which it stabilizes at this low level (with about 25-35 percent of the signal going unnoticed). The distribution of attention also has great significance. Practice has shown that work with banked machine tools and the work of transport drivers and air traffic controllers require a capability for distributing attention among many objects simultaneously. Also significant, in addition to the distribution of attention, is switching of attention, where special signals cause the attention to be switched from one object to another, as happens in the work of an operator at a control console.

Figure 52 shows how the pilot of a piston-engined training airplane distributes and switches his attention (K. K. Platonov, 1970). According to B. A. Yakubov's data (1970) the number of eye and head movements and, consequently, the number of times the attention is switched is many times lower for experienced pilots than for less-experienced pilots in the same flight conditions, as can be seen from Table 23.

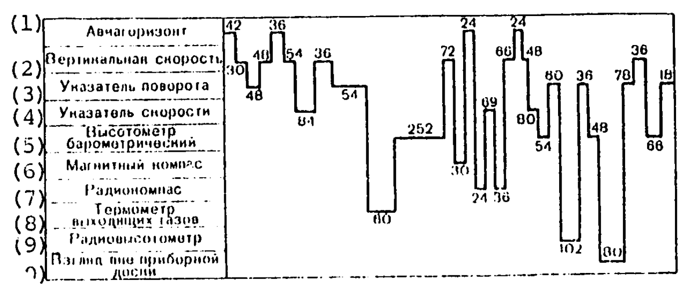


Figure 52. Movement of Pilot's Gaze in Horizontal Flight: Numbers indicate gaze fixation time in hundredths of seconds (Yu. A. Petrov, K. K. Platonov, A. F. Pospelov, 1954). Observation time is 30 seconds

Key:

1. Artificial horizon
2. Vertical speed
3. Turn indicator
4. Air speed indicator
5. Barometric altimeter
6. Magnetic compass
7. Radio compass
8. Exhaust thermometer
9. Radio altimeter
10. Looking at other than the instrument panel

Table 23. Motion Picture Photography of the Eyes and Movements of an Individual in Flight (B. A. Yakubov, 1970)

Pilot's Class	Filming Time	Number of Movements	
		Eyes	Head
1st	14 min 08 sec	12	5
3d	17 min 50 sec	172	54

Attention volume--that is, the number of objects embraced by the attention simultaneously--has great significance. Research has shown that attention volume may be equal to a maximum of four to six objects, simultaneously embraced by the attention. However, the literacy level has great significance to what is defined as the object. To an illiterate person, every letter of a word is an independent object, while to a literate person whole words rather than letters are objects of attention.

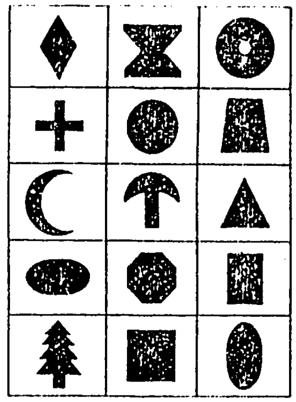
Interpreting the individual as a communication channel with stimuli at the inputs and responses at the outputs, and analyzing reactions from the standpoint of information transmission rate, the well known English psychologist G. A. Miller (1956) came to the conclusion that the volume of direct perception does not depend on the quantity of information in the isolated stimulus, being determined instead by the length of the series of units presented, the limit of which is 7±2. This premise is known in psychology as Miller's law. Many authors have measured the volume of information reproduction using binary numbers, decimal numbers, individual letters of the alphabet, syllables, one-syllable words not associated in meaning, and shape. They all obtained data falling within the limits of Miller's law. When presented once, an individual is capable of memorizing and recalling an average of nine binary numbers, eight decimal numbers, seven letters of the alphabet, seven shapes and five one-syllable words.

It was interesting to clarify, however, exactly what would happen when the series of presented information exceeded Miller's law, and to trace the dynamics of accompanying absolute information recall and the volume of relative information recall. This work was done by S. I. Gorshkov, N. A. Kokhanova and L. A. Krastina (1967).

They used two types of visual stimuli: Individual words and figures not associated in meaning but grouped together into sets, beginning with six and ending with 30 words and figures. An example of a set of figures and words is shown in Figure 53.

One set of words and figures was shown successively to a group of five to eight subjects, who were told to memorize them. Immediately after the showing all subjects wrote down the words or drew the figures.

The research showed that the dynamics of absolute reproduction of words and figures contained in sets of varying size follow a certain law. A set consisting of not more than five words or figures is recalled without error. Just by increasing the size of a set to six stimuli, we can cause a 13-17 percent frequency of recall error in the case of words and a 4-10 percent error in the case of figures. As the number of stimuli in a set increases, this error grows, attaining a maximum of 35-48 percent with 15 words and 6-17 percent with 15 figures. We can see on comparing sets containing identical quantities of words and figures that the quantity of recalled



(1) Микроскоп	Поезд (11)
(2) Туман	Геройство (12)
(3) Люди	Свобода (13)
(4) Художество	Номер (14)
(5) Молоко	Жизнь (15)
(6) Источник	Путешествие (16)
(7) Гипертония	Станция (17)
(8) Повторение	Работа (18)
(9) Продолжение	Линейность (19)
(10) Совет	Добродетель (20)

Figure 53. Sets of Figures and Words Used in the Study. Each Figure and Each Word Was Presented Individually

Key:

1. Microscope	11. Train
2. Fog	12. Heroism
3. People	13. Freedom
4. Art	14. Number
5. Milk	15. Life
6. Source	16. Journey
7. Hypertension	17. Station
8. Repetition	18. Work
9. Continuation	19. Linearity
10. Advice	20. Benefactor

figures is always significantly greater than the quantity of recalled words. Beginning with a set of 15 stimuli, absolute recall of both words and figures grows (Figure 54), reaching 57-68 percent for words in a set of 30 stimuli and 95-98 percent for figures. In this case the percentage of recalled figures grows faster than the percentage of recalled words. This property may be capitalized on when choosing a method by which to present information: Visual information contained in figures is memorized better than that represented by written words.

Analysis of relative recall of words and figures showed that relative recall persists even after the limit of absolute recall is very much exceeded. By increasing the number of stimuli in a set, we in a sense stimulate recall of a larger volume of information. The possibility our brain has for receiving and recalling information, when it is presented in a large volume, may be capitalized on successfully both in training and in production activity. The value of this technique increases significantly in connection with the possibility for reducing error in repeat experiments involving the perception and recall of large quantities of visual stimuli.

The obtained data, indicating that the volume of information recalled increases as the volume of information presented increases, may enjoy application in ergonomic organization of signal information at control consoles, and in industrial safety.

Similar data were published by S. I. Bogarova in 1977.

The time of information presentation--that is, the time information is allowed to affect human senses prior to its recognition--has great significance to its perception. As had been noted earlier, this time can be determined with a tachistoscope (see above).

In addition we (10) studied the significance the total volume of the information field or the total number of numerical symbols within it, the linear dimension of the displayed figure and the nature and "strategy" of visual search have to perception of information and to the successfulness of visual search. The stimuli we developed for this purpose were square number tables (Figure 55) with three density levels--5, 10 and 25 numerical stimuli, which were in turn subdivided into three types depending on the linear dimensions of the numbers--5, 10 and 15 mm. The information field consisted of four tables of the same kind arranged in pairs (two above, two below); in one variant the subject was allowed to search for the necessary numbers without restrictions, while in the other he had to inspect each of the four square tables successively and independently.

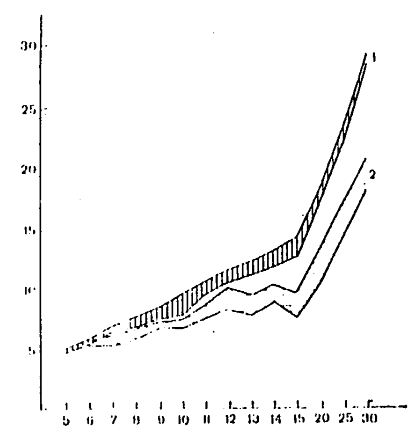


Figure 54. Nature of Absolute Recall of Words and Figures in the Presence of a Constantly Increasing Number of Signals: 1--figures; 2--words; ordinate--number of correctly recalled elements; abscissa--number of elements in a set

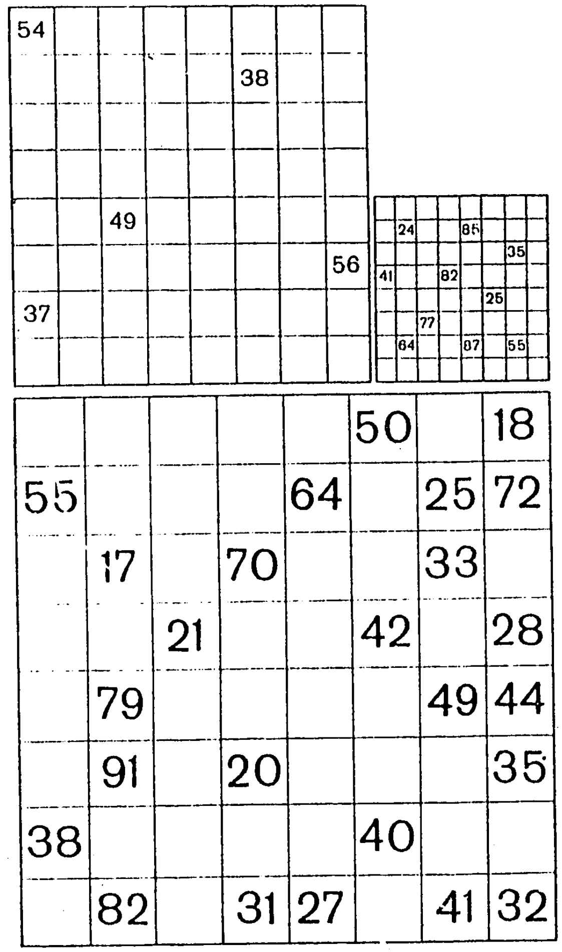


Figure 55. Table Used to Determine Dependence of Speed and Precision of Information Search on the Dimension of Numerical Stimuli and on Their Number (Each Table Represents a Fourth of the Information Field)

The research established that the average search time (Table 24) and the number of errors grow significantly with an increase in the number of numerical stimuli in the information field; consequently the time and precision of search are a function of the total number of signals and the volume of information in the information field.

Next we discovered a dependence between search time and precision and the linear dimensions of numerical stimuli in the table, expressing itself as growth in the speed and precision of search with growth in linear symbol dimensions. In other

Table 24. Dependence of Information Search Time and Precision on the Linear Dimensions of Signals, on Their Number in the Information Field and on the Nature of Search

(1) Количество сигналов в ¼ информационного поля	(2) Линейные размеры знаков, мм	(3) Поиск последовательно в каждой четверти информационного поля		(6) Поиск свободный в общем поле	
		(4) время, с	(5) количество ошибок	(4) время, с	(5) количество ошибок
5	5	18,8	0,2	10,95	0,23
	10	13,2	0,1	10,2	0,10
	15	10,0	0,05	7,2	0,2
10	5	22,8	0,36	18,1	0,3
	10	21,9	0,30	15,6	0,0
	15	20,3	0,1	14,1	0,2
15	5	44,1	0,65	25,1	0,12
	10	42,2	1,13	34,8	0,52
	15	40,5	0,65	19,0	0,06

Key:

1. Number of signals in one quarter of information field
2. Linear symbol dimensions, mm
3. Searching each fourth of information field successively
4. Time, sec
5. Number of errors
6. Searching the entire field without restrictions

words we discovered these parameters to be dependent on the distinguishing characteristics of the signal. However, the number of signals in the information field is found to have greater influence. Thus while decreasing the linear dimensions of the numerical stimuli by a factor of three caused the search time to increase from 40.5 to 44.1 sec (by 9 percent), increasing the quantity of stimuli by a factor of five caused the search time to increase from 13.8 to 44.1 sec (by 300 percent), or in the other variant from 10 to 40.5 sec--that is, by a factor of four.

Search precision and primarily its speed increase significantly with unrestricted search for the needed signal in the information field. Unrestricted search was found to be more effective. The precision and accuracy with which information is received in these cases depends to a significant extent on the perception "strategy," which is defined mainly by the route taken or by the sequence in which the objects are perceived, and by the way the algorithm is optimized. Organizing the spatial and temporal sequence of scanning the information field should be viewed as one of the effective ways for optimizing information input (B. F. Lomov). Apparently there are "hidden reserves" for increasing the operator's "capacity" in this direction. But at the same time when the operator's activity is subordinated to rigid, unambiguous rules, conditions are created which may keep the operator from realizing his possibilities and his reserves.

Many researchers have come to such a conclusion. Thus Hacker (80) conducted interesting research that led to the conclusion that activity must be planned in such a way as to ensure, figuratively speaking, a certain number of degrees of freedom to the operator in the performance of this activity. An indirect confirmation of this conclusion can be found in data of the West German flight safety service, which established that one of the reasons for accidents in the air is "standardization of pilot thinking" (B. F. Lomov, 1977).

P. K. Anokhin provides the fullest possible description of the physiological mechanisms associated with perception of particular signals.

Anokhin came up with his ideas about afferent synthesis with the purpose of revealing, to the fullest extent possible, the way information is received and the conditions responsible for formation of conditioned reflex activity, including that associated with work. I. P. Pavlov himself felt that the afferent division of the nervous system played the central role in reflex formation. The dominant role played by the afferent function is also confirmed by morphological data, according to which the quantity of afferent fibers is five to six times greater than the quantity of efferent fibers. This vast afferent system allows the organism to receive detailed information on events occurring both within and without the organism.

Anokhin classifies different afferent influences in relation to their significance to formation of the organism's behavioral act in the following way: situational, triggering, and afferent feedback. Situational afferentation is defined as the sum total of all external influences affecting the organism during formation of reflex activity, including that associated with work. When afferentation is defined in this way, it should include the sanitary and hygienic conditions of the workplace, the organization of the workplace itself, all production esthetics, the work posture and so on. All of these afferent influences, which make up the situation within which labor proceeds, significantly influence its course. If we use the latent time of the auditory-motor reaction as a performance indicator, then intense production noise may dramatically increase this time, as a result of which the speed with which work operations are performed would be reduced significantly. An uncomfortable work posture may have a similar affect. Thus according to data obtained by Gorshkov and Kalinina (17) in research on the work of spinners, an uncomfortable work posture associated with mending broken yarn strands, which happens 1,500-2,000 times per shift, reduces the strength of muscles maintaining an erect posture by 10-15 percent, and endurance by 20-30 percent.

On the other hand presence of normal sanitary and hygienic conditions, compliance with the rules of production esthetics and proper organization of the workplace create situational afferentation which promotes perception of the largest volume of production information and the greatest speed of work operations while concurrently maintaining high performance for a long period of time. Thus for example, use of ear protection by weavers to reduce the effects of noise from the looms decreases the latent time from 308 msec without ear protection to 255 msec; faster performance of work operations is another result. Music broadcasts also help to create favorable situational afferentation.

From this point of view the nature of situational afferentation acquires significance as an important indicator of the sanitary-hygienic conditions, production esthetics and real scientific organization of labor. Hence it follows that establishment of situational afferentation at a level favoring effective perception of production information and high performance is an important task of labor physiology and ergonomics.

The second form of afferentation involved in afferent synthesis is so-called triggering afferentation; it is defined as a stimulus which, by releasing an arousal mechanism in the central nervous system, causes arisal of a reflex act and, if the labor is the topic of conversation, a work act. In work, triggering afferentation may be represented by a command, some sort of signal, a time-triggered reflex and so on. Because the intensity and expressiveness of a reflex act depend to a greater extent on the intensity and expressiveness of the afferent triggering effect, by regulating the latter we could significantly regulate the reflex act itself. The significance of regulating triggering afferentation in work may be demonstrated by the following examples. If rhythmical supplementary signals, for example acoustic or light signals, were to be transmitted during performance of some sort of work act, operating as triggering afferentation, these signals would make the work more rhythmical, thus significantly facilitating its performance, as can be judged from the compression seen on electromyograms--that is, from the decrease in duration of the electric activity of working muscles. Such data have been cited many times, particularly in the works of S. A. Kosilov, N. N. Khavkina, Z. M. Zolina and other researchers.

Labor physiologists have studied triggering afferentation in a number of production experiments: Using special signals, they periodically informed their subjects about their progress in a production assignment. These signals also made the work more rhythmical and raised its productivity. It is also known that when triggering afferentation is expressed in the form of some sort of signal (light, sound, appearance of the next part on a conveyor belt and so on), the way the corresponding work act is performed will depend on the intelligibility of the signal and on its intensity. Thus by adding a supplementary acoustic or light signal indicating appearance of the next part on a conveyor belt, we can improve the coordination of work on the conveyor.

It is also known that a supplementary light signal in the location of a loom that has stopped or in the zone of a broken strand on spinning, warping and other machines promotes faster mending and start-up (15).

Many more examples can be cited to show the great significance of triggering afferentation and its significance to a reflex act, including a work-associated act.

In particular, our research was aimed at studying not only triggering afferentation but also supplementary preliminary afferentation in relation to the readiness of central and neuromotor structures, the effectiveness of activity and information interaction in a "man-machine" system (9-11,15; I. M. Volkova, B. M. Kulumbetov, 1974; I. M. Volkova, 1978; I. M. Volkova, S. I. Gorshkov, 1978).

Automation of different industrial sectors is increasing the importance of sensory and mental functions in work associated with observation, signal anticipation, information retrieval and so on. In this situation, preparedness for emergency and effective actions, which are among the dominant factors defining the reliability of a "man-machine" system must be maintained.

An operator's activity would be tense and uneconomical if he had to maintain a necessary state of readiness for a long period of time (by means of nonspecific activation ensuring a high level of functional mobilization). It was in this connection that we studied one of the factors optimizing the psychophysiological conditions and raising the effectiveness of the operator's work functions and his functional comfort--the influence of supplementary afferentation brought into motion by stimuli preceding the triggering signal (by 0.5-15 sec). In addition (using a "Nihon Kohden" unit) we studied the optimum anticipation time of a supplementary afferent influence, and the way a state of readiness and attention, viewed as a psychoneural process, affects electric activity in the central nervous system and the neuromotor apparatus.

The research showed that when supplementary stimuli (sound or light) are included in the experimental model prior to a signal triggering sensomotor activity, the central and neuromotor apparatus are pretuned (Figure 56). This pretuning, this readiness for action manifested itself as a shortening of the latent time of the motor response by 30-50 msec (Figure 57), as an increase in the level of activation (according to EEG data) predominantly in the precentral region, as a decrease in this level in the temporal region coupled with a simultaneous increase in the total energy of the δ- and Θ-rhythms and less so of the β-rhythm and a decrease in the α-rhythms of the occipital region, as arisal of intentional tonic EMG activity in the preliminary phase, and as a shortening of the time of bioelectric activity of muscles in the right hand responding to the triggering signal (Figure 58). In this case the latent time of preliminary bioelectric activity of the indicated muscles clearly increases as the interval between the preliminary and triggering stimuli grows (Figure 59). However, such a direct dependence between growth in the interstimulus interval and the latent time of the response is absent. At the same time, as growth occurs in the latent time of preliminary EMG activity, which in a sense coordinates itself with the moment of the triggering reaction, the amplitude and frequency of oscillations increase in parallel, indicating that postponement of an intentional reaction correlates with growth in its intensity (Table 25). This is obviously a case of engagement of the mechanisms of probabilistic prediction of events, of prediction of the moment of their occurrence in time, permitting the operator to reduce his psychophysiological attention, distributing his attention more efficiently and raising his functional effectiveness.

Research showed that the excitability of cortical and neuromotor structures and the degree of functional mobilization depend on the interval between the supplementary and triggering stimuli, and that it is phasal in nature. Optimum anticipatory intervals were 2 sec for the flexor of the right index finger, 3 sec for the extensor and 7 sec for both muscles moving the right index finger, while 1, 5 and 15 sec were found to be the least optimum. In this case the response to light was shorter and the response to sound was longer.

Addition of supplementary signals in another type of activity of greater complexity--information retrieval--reduces retrieval time by an average of 1.2-1.5 sec (20-25 percent) and the mistakes made by 56-78 percent--that is, by 2.5-4 times. It was found in this case that 5 sec was the optimum anticipatory time of the supplementary signal and that 10 sec was less acceptable (Table 26). Consequently the optimum "anticipatory" intervals differ in relation to different forms of activity, and they are apparently specific to each type of activity.

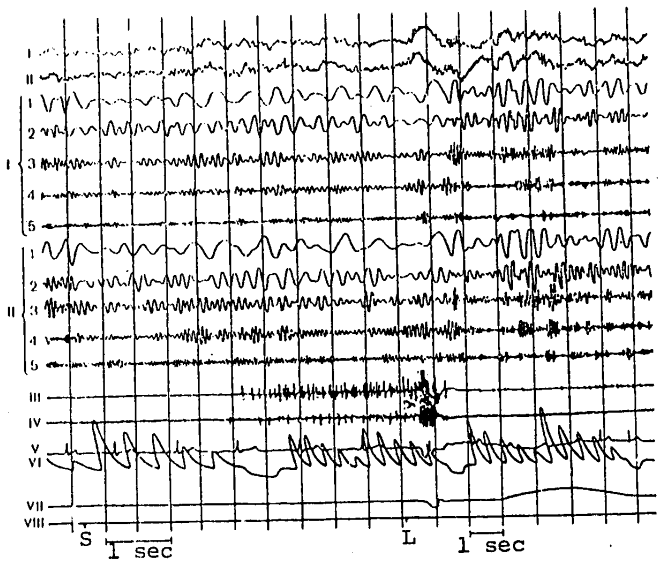


Figure 56. Electrographic Expression of the State of Readiness in the Preliminary Interval: I--EEG of temporal region of left hemisphere; II--EEG of motor region of left hemisphere; I_1--δ, I_2--θ, I_3--α, I_4--β, I_5--β_2: principal EEG rhythms of the temporal region; II_1--δ, II_2--θ, II_3--α, II_4--β, II_5--β_2: main EEG rhythms of the motor area; III--EMG recorded from flexor of right index finger; IV--EMG recorded from extensor of right index finger; V--EKG; VI--integral bioelectric activity; VII--GSR; VIII--stimulation marks; S--preliminary stimulus: L--triggering stimulus

We believe that the observed phasal activity reflects a fundamental biological law, according to which the nature of changes in the organism's reaction is governed by quantitative changes--by the "anticipatory" time in this case, while the modality and specific features of the stimulus determine the level and absolute value of the reaction.

During retrieval--that is, during performance of a required assignment, the EEG rhythms of different regions of the brain undergo complex alteration. We revealed unidirectional changes in the bioelectric activity of frontal (the most pronounced) and occipital regions of the brain: As the subject proceeded on his required assignment, electric activity exhibited a higher level of integration, with the exception of the α-rhythm, the level of which decreased. At the same time in the precentral region, which differed in the direction of changes occurring, not only the α- but also the β_1- and β_2-rhythms decreased, while the total energy of the δ- and θ- rhythms concurrently increased. This may be interpreted as a sign of a decrease in functional possibilities, a reduction of excitability in the precentral region, which does not participate in regulation of complex mental activity, and an increase in activation

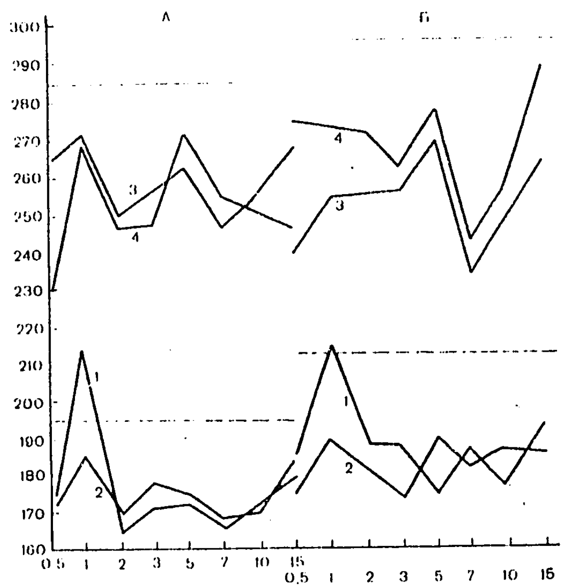


Figure 57. Dynamics of the Latent Time of Responses of the flexor and Extensor to a Single Triggering Stimulus and to a Stimulus Preceded by Preliminary Signals, Depending on Signal Modality and the Interval Between Signals: A-- flexor; B--extensor; 1--light-light; 2--sound-light; 3--sound-sound; 4--light-sound; ordinate--motor response latent time, msec; abscissa--interval between preliminary and starting stimuli, sec; broken line in upper part of figure indicates latent time of response to sound; broken line in lower part indicates latent time in response to light

of mainly the frontal and then the occipital regions of the cerebral cortex, which do take a direct part in psychosensory activity and in performance of logical operations.

Such a dramatic difference in the directions taken by changes in the EEG rhythms within the brain regions analyzed was not revealed when a preliminary signal was transmitted at the time the subject was in a state of readiness. An increase in activation was observed in the precentral region in this case as well: Here again, the conditions of the experiment were such that the neuromotor apparatus was brought to a state of readiness, as was manifested on the EMG in the form of intentional, tonic activity. When the central nervous system was in its stage of readiness--when it was mobilized--the total electric activity of the main EEG rhythms, except the δ-rhythm, was typically higher, while in the stage of most effective search the integral level of the δ-rhythm increased as well. It was found that the direction of changes in the δ-rhythm occurring in the stage of readiness and in the stage of information retrieval was opposite. Perhaps in this case the δ-rhythm reflects the informational component of the mental act and carries the information load.

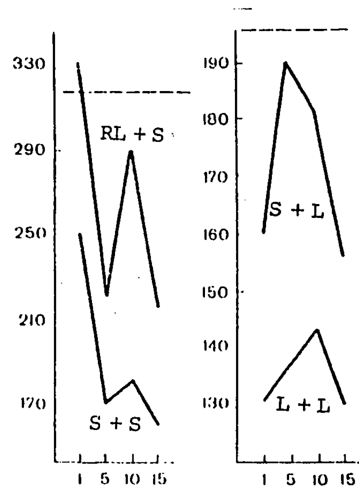


Figure 58. Time of EMG Response of Flexor Depending on Modality of Signals and the Interval Between Them: Ordinate--EMG duration, msec; abscissa--intervals between preliminary and triggering stimuli, sec

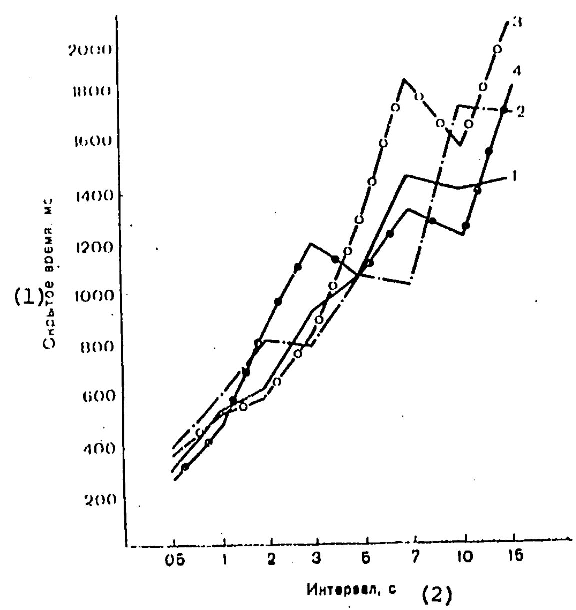


Figure 59. Dynamics of the Latent Time of Extensor Intention Depending on Modality of Signals and Intervals Between Them: 1--light-light; 2--sound-light; 3--red light-sound; 4--sound-sound

Key:
1. Latent time, msec
2. Interval, sec

Table 25. Frequency and Amplitude of Intentional Activity Depending on Modality of Stimuli and Interval Between Them

(1) Модальность	(2) Интервал, с	Сгибатель (3)		(4) Разгибатель	
		(5) амплитуда, мкВ	(6) частота, с	(5) амплитуда, мкВ	(6) частота, с
Звук+звук (7)	1	0	0	0	0
	5	6,3	24	6,0	20,8
	10	7,5	31	6,2	21,4
	15	10,0	34,0	7,6	26,2
Свет+свет (8)	1	0	0	5,0	26,0
	5	6,0	20,6	7,0	28,6
	10	6,0	31,4	7,0	29,0
	15	0	0	6,3	30,0
Красный свет+звук (9)	1	0	0	5,0	24,0
	5	7,0	25,2	8,0	28,8
	10	7,7	30,6	7,5	26,0
	15	9,0	31,0	12,0	38,0

Key:
1. Modality
2. Interval, sec
3. Flexor
4. Extensor
5. Amplitude, μv
6. Frequency, sec
7. Sound + sound
8. Light + light
9. Red light + sound

Table 26. Dynamics of Change in Visual Search Time and Errors, Based on (Gryunbaum's) Table, in the Presence of Supplementary Afferentation and Without It

(1) Регистрируемые показатели	(2) Без дополнительной афферентации	(3) С влиянием дополнительной афферентации					
		за 5 с (4)			за 10 с (5)		
	M±m	M±m	T	p	M±m	T	p
(6) Время поиска, с	6,33±0,24	4,87±0,36	3,3	⩽0,02	5,14±0,50	2,2	⩽0,05
(7) Ошибки	8,86±2,21	2,00±0,56	3,0	⩽0,02	4,00±0,60	2,2	⩽0,05

Key:
1. Recorded indicators
2. Without additional afferentation
3. With supplementary afferentation
4. In 5 sec
5. In 10 sec
6. Search time, sec
7. Errors

Of interest is the fact that when information retrieval is most successful (when the anticipatory time of the supplementary signal is 5 sec), the integral level of the total energy of the analyzed frequency is higher than the level observed in the readiness stage; on the other hand when information retrieval is less successful (with an anticipatory interval of 10 sec), the integral level is lower. Moreover when retrieval was most effective and, equally so, more complex, the total energy of the main frequencies (especially the δ-, Θ- and β-rhythms) increased more significantly than when it was less effective or simpler.

And finally, while the level of activation increased in both the frontal and occipital regions when retrieval was more successful, when it was less successful this increase was typical of only the frontal points of contact, with activation decreasing in the occipital region. Apparently in the latter case the coherence of the potentials recorded from the frontal and visual regions of the cortex decrease significantly, especially in relation to rhythms of the β- and Θ-ranges.

The distinct relationship existing between the higher Θ- and especially δ-rhythms on the background of pronounced high frequency β-activity and the greatest successfulness and productivity of retrieval provides the grounds for hypothesizing that this increase in the noted EEG components is a correlate of effective mental activity (9).

Moreover it was demonstrated that in other types of activity as well, in which higher mental functions dominate, the level of activation of cortical structures and the degree of functional readiness also depend on the size of the interval between the supplementary and triggering stimuli.

Anokhin's functional system theory (2,3) can be used as the starting point for revealing the mechanism behind the state of readiness created by supplementary afferentation, and its functional structure. According to this theory the interval between a stimulus "triggering" some sort of activity, for example information retrieval, and the response--that is, completion of retrieval, must be when afferent synthesis (predetermination) and decision making occur; these processes are systemic in nature, and they require simultaneous--and not successive--activity of elements taking part in these processes. In this case afferent synthesis may be interpreted as convergence of different types of information at the same integrative neurons. Efferent-afferent conversion, which was found to play an important role in prediction of the result of activity (P. K. Anokhin, 1974), is especially interesting. The activity at the output of these cells reflects, in processed form, integration of afferent influences. Thus by tuning neurons to a state of higher excitability, by raising the reactivity of neuron systems, a preliminary stimulus (information 1) promotes more successful afferent-efferent integration; next, the triggering stimulus (information 2) "starts up" a particular system of mutual relationships between different structures that had already come into being prior to this action in the form of "preliminary integration" (71,72; P. K. Anokhin, 1949).

Thus our results provide the grounds for suggesting that a state of readiness for activity, or "anticipation," which is associated with higher reactivity of neuron systems, promotes successful afferent-efferent integration, and that it may be used to develop the criteria by which to evaluate functional mobilization and mental tension.

We believe that the obtained data on the dynamics of cortical EEG rhythms and of the EMG activity of working muscles, as well as the successfulness of performing different forms of activity and their mutual associations, both without supplementary afferent stimulation and with its influence, provide a way for objectively evaluating the functional structure of the types of activity under analysis and for revealing the mechanisms responsible for the operator's state of readiness and the effectiveness of his work.

Our laboratory studies were tested and confirmed in production conditions, in which supplementary afferentation, brought about by the inclusion of signals informing the operator of problems in the production process, resulted in fast mobilization of functions, faster performance of production operations, lower nervous and emotional tension, and 12-18 percent greater functional comfort and work effectiveness.

The obtained results attest to the need for broadly introducing supplementary warning signals when organizing workplaces and planning equipment in different industrial sectors with the purpose of raising the reliability of man-machine systems and increasing labor productivity.

The last link of afferent synthesis--afferent feedback, which can be defined as the sum total of adaptations by means of which the organism obtains information on the degree to which reflex acts, including work acts, correspond to their intended purpose--is no less significant to revealing the physiological mechanisms of information perception. Anokhin attaches great significance to stage-by-stage afferent feedback, considering that a reflex reaction, including one associated with labor, proceeds not as a single entity but in the form of successive actions.

Our ideas about so-called chain reflexes must be reexamined from the standpoint of stage-by-stage afferent feedback. Interpreting some work action consisting of a number of successive operations (acts), we had formerly interpreted it as a chain reflex in which the end of one operation is a stimulus for the beginning of another operation. But this interpretation lacks a significant element--afferent feedback indicating the end of each link, without which the next link cannot proceed. From this point of view a detailed analysis of a chain reflex, for example that made by Prof A. I. Krestovnikov (1954) of jumping over a bar, must be supplemented by afferent feedback indicating the end of a previous movement included within such a jump.

That such stage-by-stage afferentation does in fact exist may be demonstrated with the example cited by N. V. Zimkin (in a report to the Fifth Conference on Labor Physiology, 1967). Analyzing the simple operation of depressing a key in response to a periodically repeated audible click, he discovered that the key may be pressed before or after the click. The significance of stage-by-stage afferent feedback is clearly evident here, because the time interval until the next pressing of the key is corrected depending on whether the key had previously been pressed before or after the click. Such correction can be performed only with the help of instantaneous afferent feedback.

These examples of the significance of different forms of afferentation, and of afferent synthesis in general, developed by P. K. Anokhin in relation to labor, emphasize the significance of correctly understanding the physiological mechanisms proceeding in labor activity and in the course of perceiving production information. On the other hand if we consider the significance of different forms of afferentation and of afferent synthesis in general, and if we account for the unique features of such afferentation, within certain limits we can achieve control over work acts, make them easier, and create conditions promoting maintenance of high efficiency over a long period of time. Such application of our ideas about afferent synthesis makes them significant as a factor in regulation of labor; consequently labor physiologists and ergonomists should make broad use of afferent synthesis.

Asratyan's ideas about switching factors and tonic reflexes have great significance to an understanding of the role of informational interaction in labor.* These ideas essentially entail the following. It was discovered in work with conditioned reflexes that the same conditioned stimulus may have different informational significance depending on the conditions under which it is applied. Thus a metronome set at 120 would be a conditioned feeding stimulus when used in the morning in the presence of alimentary reinforcement, but when used in the afternoon together with painful reinforcement it becomes a conditioned avoidance stimulus. In this case change in the informational significance of the reflex--that is, its switching, depends on the time of the day in which the reflex occurs--in the morning it is a feeding reflex, while in the evening it is an avoidance reflex. This switching may be elicited by other environmental factors, for example by the experimenter himself; in Asratyan's conception, such an environmental factor was named a "switching" factor.

We all know for example that the bell at our places of work has different significance depending on the time of day it is rung: In the morning it tunes us into work, while at the end of the day it tunes us to quickly finishing our work and going on to other things not associated with work. In this case the time at which the bell is rung is the switching factor.

Evaluating the physiological significance of switching factors as stimuli, Asratyan isolates them from triggering stimuli as a special group, the main feature of which is their prolonged or, as Asratyan called it, their tonic action. Switching factors or tonically operating stimuli are encountered very frequently in labor physiology and ergonomics, as can be demonstrated with a number of examples.

The most typical example of a switching factor or tonic stimulus in relation to man is preliminary instructions. Once they are made known, they operate for an indefinitely long time interval, for practical purposes until they are superseded by other instructions.

Asratyan deserves credit for the fact that he and his colleagues were able to analyze the physiological mechanisms behind development of switching factors and the performance of tonic reflexes, since their work now allows us to understand the significance of switching factors (instructions in particular) to the mechanisms behind perception of production information and labor.

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*Asratyan, E. A., "Lektsii po nekotorym voprosam neyrofiziologii" [Lectures on Some Problems of Neurophysiology], Izd-vo AN SSSR, 1959.

It should be pointed out that all of the sensomotor reactions used in our experiments, including visual-motor and audiomotor, are examples of reactions to instructions. Although the instructions used in these cases were very simple--"raise your finger from the key when you see a light, hear a sound or sense some other stimulus"--nevertheless these instructions are an example of a tonic--that is, long-acting--stimulus: While it does not elicit a response on its own, were it to be absent, neither would there be a response to a light, sound or some other stimulus operating on its own.

The physiological mechanism of tonic stimulation was revealed by G. T. Sakhiulina from Asratyan's laboratory. It was found that bioelectric activity rises in that region of the cortex toward which the action of the tonic stimulus is directed. Arisal of an excitation focus may obviously be explained both by the mechanisms of switching and tonic action and by the previously revealed fact of the dramatically shorter latent time of a reaction to the crossing of a certain point on the scale of an instrument by a moving pointer, or in general to a moving light stimulus.

By accounting for the physiological mechanism of switching factors and tonic stimuli, revealed by Asratyan and playing a major role in work actions performed in response to instructions, we can examine, with greater understanding, a large category of work acts and physiological mechanisms of information perception.

When we study the physiological mechanisms of informational interaction, we treat the mechanism behind formation of the individual's responses as the last link in such interaction. In our initial approach to this question we must keep in mind that afferent feedback is at the basis of this mechanism. Thus A. F. Samoylov pointed out as long ago as in 1930 that while a person holds a pencil and writes, motor impulses travel from the spinal cord to the muscles of the hand, and that impulses concurrently travel along nerves to the spinal cord from sensory terminals contained in muscles; these impulses provide reflexive feedback, allowing the operator to monitor muscle innervation. According to S. A. Kosilov (1938, 1954, 1955, 1957, 1965) feedbacks accompanying work actions are monitored consciously, in accordance with the operator's idea as to the goal of his work and the correct, most effective pathways of its attainment. Moreover operators guide themselves by sensory stimuli below the threshold of their consciousness. These stimuli permit operators to attain high precision in their work movements. Kosilov coined the concept "integral image of work actions" to represent the neural processes occurring in the cerebral cortex that make up the physiological basis of these ideas and the unconscious correcting stimuli. In Kosilov's opinion the integral image of work actions differs from the integral image concept introduced into science by A. A. Ukhtomskiy (1923) in that his includes the goal of labor and participates in the circular reflex cycle of the second signaling system. The integral image of a work action is a concept having to do with the work acts of the individual as part of society, while Ukhtomskiy's integral image has to do with the instinctive behavior of animals and man.

P. K. Anokhin analyzed the response evolution mechanism more deeply in his functional system theory, developed by him back in 1935 in the book "Problema tsentra i periferii v fiziologii nervnoy deyatel'nosti" [The Problem of the Center and the Periphery in the Physiology of Nervous Activity]. Anokhin applied the concept "functional system" to the product of integration of partial mechanisms--a principle so necessary to an understanding of the integral organization of nervous activity.

The functional system is based on Anokhin's ideas on afferent synthesis discussed above, and on the associated idea of the acceptor of action. The acceptor of action concept is, in Anokhin's opinion (1968), the key mechanism of the functional system which lies at the basis of decision making--that is, formation of a response to incoming information. In Anokhin's opinion decision making is a logical process of the functional system, but at the same time it is a result of fully determined physiological processes. The essence of these processes is that the organism must inevitably choose the sole possible line of behavior (reaction) from numerous possibilities facing it at the given moment. No matter what the conditions are, the organism has a possibility for selecting a fully definite act and excluding all other potential possibilities. Ukhtomskiy (1945) referred to this process in application to the muscle system as "elimination of surplus degrees of freedom." In Anokhin's opinion the physiological meaning behind "decision making" in relation to formation of a behavioral act can be stated as follows: 1) decision making is the result of afferent synthesis; 2) decision making frees the organism from a large number of degrees of freedom and thus promotes integration of efferent expectations, ones necessary to the organism and having adaptive meaning to it at the given moment and in the given situation; 3) decision making occurs in a moment of transition, following which all combinations of excitations acquire an actuating, effector nature.

To understand how a choice is arrived at in decision making, how degrees of freedom are eliminated, Anokhin created the idea of the so-called acceptor of action, which he defines as the afferent machinery that monitors information on forthcoming results. This machinery forms a response beforehand in its effector expression, and consequently it anticipates the response by a certain interval of time. The physiological mechanism behind the "acceptor of action" in application to man can be described as arisal of the "intention to act" at the moment afferent synthesis reaches a conclusion. This predetermines the subsequent physiological role of the acceptor of action, which accepts, in the form of afferent feedback, all afferent stimuli arising as a result of actions. The "acceptor of action" machinery compares the results of afferent synthesis--that is, the plan of action--with the results of the work act. Coincision of these stimuli terminates the entire cyclic process of response formations, while their "mismatch" elicits an entire series of new reactions which must in the end lead to a reflex response corresponding to the nature of the "acceptor of action." The mechanism behind formation and operation of the "acceptor of action" is shown in Figure 60.

Anokhin (1968) worded the law of formation of the acceptor of action and its role as follows: "In all cases where the brain transmits stimuli through terminal neurons to peripheral working organs, simultaneously with the efferent "command" a certain afferent model forms, capable of anticipating the parameters of the future results and comparing, at the end of the action, this prediction with the parameters of the true results."

This law has special significance in the case of complex human behavioral acts. In this case the most diverse goals of behavior may be posed, but even so, the "acceptor of action," formed at the moment of decision making, is still able to subsequently determine the degree to which the plan coincides with the results. Prediction of the results of action is a universal function of the brain that prevents arisal of all sorts of "errors"--that is, it keeps actions not corresponding to the goal posed by the organism from happening. The only way harmonious behavior could be structured and mistakes could be avoided would be to constantly compare the

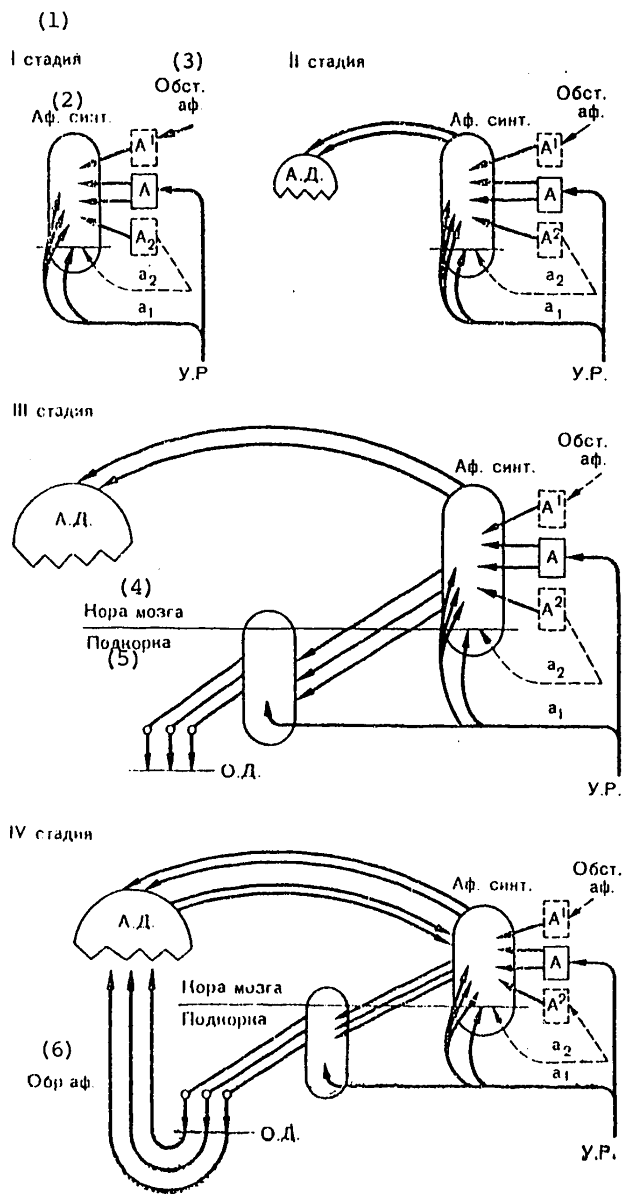

Figure 60. Successive Stages of Developing a Firm Conditioned Reflex in Response to a Conditioned Stimulus: Stage I--synthesis of all diverse internal and external afferent influences upon the organism; A--triggering stimulus analyzer; A^1 and A^2--situational stimuli for different analyzers; a_1 and a_2--collateral action of triggering and conditional stimuli upon the brain stem reticular formation; У.Р.--conditioned stimulus; stage II--formation of the acceptor of action on the basis of afferent traces remaining from previous stimuli (А.Д.); stage III--formation of the response

(О.Д.), which always develops after the acceptor of action; stage IV--arisal of afferent feedback from all aspects and characteristics of the achieved results. In this example afferent feedback from the results of action agrees precisely with the nature of the acceptor of action--that is, the result corresponds exactly to the plan (or intention) of performing the action

Key:
1. Stage
2. Afferent synthesis
3. Situational afferentation
4. Cerebral cortex
5. Subcortex
6. Afferent feedback

results of that which has been done with the formerly predicted afferent parameters of the results.

It is evident from this whole discussion that the physiological mechanisms of informational interaction between man and equipment are rather complex. At the same time we have been able to discern certain key factors in this interaction which aid us in understanding this interaction, and subsequently accounting for and controlling it. These key factors include our ideas about the role of attention, the functions of memory, afferent synthesis and the acceptor of action. Using these ideas, we can simulate informational interaction with a certain degree of probability, and use the results of this simulation in our design of production equipment.

Man's psychophysiological and psychological characteristics must be studied not only with the purpose of resolving traditional problems--improving performance and reducing tiring, learning about the laws governing information reception and processing, discovering the memory and thinking processes associated with the control and use of equipment and so on. We must also study these characteristics so that we could develop the principles, methods and resources of controlling the individual's psychophysiological state in the course of activity proceeding with the assistance of technical devices. Development of this direction is just beginning.

The most adequate approaches are ones in which natural mutual relationships in a "man-machine-environment" system are simulated and in which man's interaction with a controlled experimental environment proceeds according to the principle of a closed loop with feedforwards and feedbacks. These requirements may be satisfied in a so-called controlled experiment (M. N. Livanov et al., 1966; P. V. Bundzen et al., 1973; V. V. Trubachev et al., 1973, etc.).

A physiological biocontrol experiment (biofeedback experiment) makes use of an automatic system in which there is artificial, experimentally controlled, external feedback between the "inputs" and "outputs" of the biological object under analysis.

Interest in research methods using feedback grew significantly in the mid-1970's, because their clear advantages not only permit us to reveal and describe certain algorithms of the activity of the brain or some functional system with the help of modern methods, the theory of automatic control and computer technology, but they also provide the grounds for highly effective training methods and directed influences having the purpose of compensating for certain impaired functions (P. V. Simonov, F. Ye. Temnikov, 1965; N. N. Vasilevskiy, 1972, 1972 etc.).

Biofeedback systems are used in automatic signaling systems to monitor man's functional state, and they can be used to analyze the brain's functional states in the clinic.

Biofeedback systems can be used to coordinate the characteristics of an external signal (or the moment of its influence) with the dynamics of certain characteristics of brain bioelectric activity or other physiological parameters. However, most authors have used the encephalogram to create closed systems controlled by changes in physiological functions. The experimental design used most often in this case is one in which illumination of the eyes is increased whenever an α-rhythm of any stability whatsoever arises. This illumination is maintained until the α-rhythm decreases, as a result of which the light source turns off automatically (T. H. Mulholland, S. Runnals, 1961; V. G. Zhukov, 1963; P. V. Bundzen, 1965). The work of such a system depends significantly on the attention of the subject. Experiments have shown that stable, calm attention is more typical of a growing α-rhythm. Depression of the α-rhythm is more typical of anxious alertness (T. H. Mulholland, S. Runnals, 1962; I. Z. Dussailly, 1963). We can see that feedback systems can be used to determine more specifically the EEG-correlates of nervous and emotional tension in man.

Feedback systems were found to be a valuable tool for analyzing the functional significance of various EEG frequencies owing to a unique sort of "instrumentalization of self-observation." For example the individual is asked to maintain a tone dependent on his α-rhythm, and then he is asked how he was able to prolong the sound. It turns out that most subjects perform this task by evoking a state of calm, of general relaxation within themselves, by thinking about pleasant things and so on (D. Nowlis, J. Kamiya, 1970).

In addition to the EEG, a feedback system may make use of oscillations in skin potentials (the GSR) and the electric resistance offered by the skin to an external current. As an example the fact that resistance decreases in the presence of fear, anger and an orientation reaction, and increases in the presence of tiring, insobriety and drowsiness (E. Z. Levy, 1961), made it possible to patent a device monitoring the way a driver feels by recording the electric resistance of the palms when in contact with the steering wheel. Growth in resistance or breaking of the circuit turns on an alarm signal (D. W. Scheer, 1962). This principle may also find broad application as well. The galvanic skin reflex may also be used in devices performing the role of a unique "psycho-electronic amplifier" for detection of a signal significant to the subject. In this case the galvanic skin response lengthens the time of exposure to the signal or blocks performance of the operator's voluntary commands (I. S. Ivanov, P. V. Simonov, 1965, 1969).

It should be emphasized that in principle it would be possible to create a system containing technical units which undergo change as the individual learns to use them. A certain amount of experience has already been accumulated in this direction--for example systems which contain a unit that monitors the state of the operator

(A. A. Vasil'yev, B. F. Lomov, 1970) and systems in which a computer determines the strategy of the individual's activity and selects, on the basis of this strategy, the information to be transmitted to the individual.

Application of the feedback principle, which ensures close cause-and-effect ties between the current functional state of the system and the result of its activity, is a fundamentally new approach, one extremely important to the creation of effective monitoring systems. This is why intensive development of the scientific foundation of ergonomics is so important.

Consideration of Psychological Factors in Ergonomics

In its recommendations, ergonomics relies on the data of the technical, social, economic and biological sciences. Among the biological sciences, labor psychology providesdata of great significance to ergonomics. Labor psychology studies the psychological features of different forms of labor and their dependence on sociohistoric and concrete production conditions within which labor proceeds. By studying labor psychology we can make use of the laws of general psychology to make work easier and to raise labor productivity by accounting for psychological characteristics in our ergonomic requirements on the designs of production equipment.

Among the problems of labor psychology having significance to ergonomics, psychologists single out: 1) the psychological features of the personality; 2) the psychological features of attention; 3) evaluation and formation of occupational aptitudes; 4) psychological study of the causes of accidents; 5) determination of the significance of initial psychological state; 6) the role of the volume of information available about work progress; 7) the role of psychological climate in production (N. N. Platonov and others).

The psychological features of the personality are defined as the sum total of significant and more or less constant features of the personality. In accordance with the dialectical-materialistic definition of psychology, the psychological features of the personality are not inborn, and as the personality develops, these features change; their expression varies depending on the concrete sociohistoric conditions. The most important psychological features of the personality are: Philosophy--that is, the system of viewpoints on the surrounding phenomena of society and nature; the interests of the personality--that is, the orientation of the personality toward certain objects and phenomena; capabilities and endowments--that is, individual features serving as conditions for successful performance of one or several forms of activity; the temperament of the personality, which may be choleric--that is, typified by fast arousal and strong feelings, sanguine--characterized by fast arousal but weak feelings, melancholic--characterized by slow arousal and intense feelings, and phlegmatic--characterized by slow arousal and weak feelings. According to I. P. Pavlov, the physiological basis of temperament is associated with certain features of nervous system types, with nervous processes of varying intensity--arousal and inhibition, with the balance between arousal and inhibition, and with mobility--the capability for transforming arousal into inhibition and vice versa. The psychological features of the personality also include traits of character--that is, the sum total of basic psychological properties of the individual, ones making an impression upon all of his actions. Initiative and conscientiousness are ones having a bearing on ergonomics.

All of the psychological features of the personality listed above play a great role in defining the position of a given personality in a social or work process. This has significance to formulating the psychological requirements of ergonomics.

The psychological features of attention have great significance to all forms of human activity. Attention can be defined as orientation of the consciousness toward a certain object or activity. The main properties of attention include its stability and diffuseness. Attention distribution has great significance. It is required, for example, by an individual operating several machine tools, by transport drivers, and by operators and traffic controllers. Also significant in addition to distribution is the switching of attention--its transfer from one object to another in response to special signals. Attention volume--that is, the quantity of objects that may be within the individual's visual field simultaneously--is an important indicator. Research has shown that attention volume has a maximum of five to seven objects simultaneously embraced by the attention. However, according to data cited by S. I. Gorshkov et al. and S. P. Bocharov, this maximum may be significantly expanded (see the section "Characteristics of Informational Interaction During the Use of Production Equipment").

In its evaluation of the formation of occupational aptitudes labor psychology basis itself on the premise that high indicators may be reached in a given form of occupational activity by workers with highly different personalities, while failure in a given occupation is usually distinctly dependent upon certain fully definite characteristics. Finding the characteristics of psychological structure which predetermine failure in an occupation is an important task of labor psychology. Correct evaluation of occupational aptitudes requires that we treat the personality features listed above as central to such evaluation. The main factors of this approach would be (K. K. Platonov, 1974): 1) understanding the psychophysiological features of the given form of labor or occupation, and particularly the causes of the most typical mistakes; 2) comparing the psychological structure of the personality under analysis with these features of the occupation; 3) making an expert conclusion on the basis of thorough comparison of these two structures, with mandatory consideration of the personality's compensatory possibilities.

If we are to evaluate an individual's occupational aptitude, we must study him in different forms of labor, to include in laboratory psychophysiological experiments.

When it comes to emergency situations, labor psychophysiology is interested primarily in the significance of the personality factors which had led to wrong actions leading to an emergency. The most common causes of wrong actions may be: 1) poor training of the worker, absence of the necessary knowledge, or its insufficiency; 2) inconsistency between the worker's individual psychological qualities and the requirements of his work--that is, weak occupational training; 3) lack of discipline or carelessness; 4) temporary deterioration of performance as a result of illness, tiring or a negative influence of the working conditions (K. K. Platonov, 1970).

In terms of research on emergency situations, labor psychology is especially interested in causes falling within the second group--that is, inconsistency between individual psychological qualities and the work being done. Their revelation is the task of labor psychophysiology and ergonomics. The same psychological methods of personality study that were indicated above in the discussion of occupational aptitudes are used here.

Initial psychological state has great significance to determination of performance level. Psychological state prior to work and in its course is a complex phenomenon; it is an expression of the personality's relationship to the work being done. It depends on the circumstances under which the individual is prepared for this work, on how stable the personality's attitude toward labor is in general, and on the aftereffects of preceding psychological states, emotional ones in particular. An initial state may have intellectual, emotional, and motor aspects (49,69). The intellectual aspect is represented mainly by the degree to which the work is comprehended and the degree to which the attention is focused on it. The emotional aspect is represented by the feelings accompanying the preparations made by each worker--his sense of alertness, confidence and eagerness for work, or his sense of tiredness, sluggishness, depression, reluctance to work and so on. The motor aspect is represented by the individual's level of motor activity, by the speed of his movements and by their precision, or by their slowness, erroneousness and so on.

Upon inspecting the aspects of initial states, we find it possible to reduce the latter to four forms: a positive state in active form, a positive state in passive form, a negative state in passive form and a negative state in active form. Research has shown that performance depends to a considerable extent on initial state. The effectiveness of work rises as psychological state varies from a negative state in active form to a negative state in passive form, and from a positive state in passive form to a positive state in active form. Labor psychology is highly significant in that it has a possibility for changing a psychological state from its negative form to a positive form, and thus raising work effectiveness by 10-15 percent.

The following figures provide an indication of the important role played by a knowledge of the volume of information on work progress. If we compare the labor productivity of two groups of workers, where one knows the volume of an assignment and the other does not, we find that the labor productivity of workers in the first group is 5-15 percent higher than workers in the second group.

According to modern ideas, the psychological climate in the work collective--that is, the sum total and nature of mutual relationships between members of the collective--has great significance to work effectiveness. The organization of the production process itself, and particularly the presence or absence of monotony, plays an important part in determining the characteristics of the psychological climate. When the organization of labor is monotonous the nervous system is inhibited, the individual experiences a sense of boredom, and he lacks interest in his work, as a result of which psychological separateness arises in the collective; taken all together, this leads to lower work effectiveness.

S. I. Gorshkov and I. A. Goncharov analyzed the state of psychological separateness in leather industry, focusing in particular on the sewing of gloves in leather industry. Leather gloves are made today as single items (as pairs) on automatic conveyors with an uncontrollable rhythm, one for each sewing operation, and on conveyors with an unrestricted rhythm, on which several workers (a maximum of eight) perform the same operation on batches of gloves. The workplaces of the workers are located along the conveyor line and at a 90° angle to it, such that throughout the entire work day the workers see only the backs of the heads of their comrades in work. Their work is characterized by a large number of fine operations and by sharp division of labor between the workers. As a consequence the workers experience reduced functional mobility of the nervous system, the boredom that arises is accompanied by frequent yawning, their notion of the end result of collective labor vanishes, their sense of responsibility for the work decreases, and the workers become separated from each other technologically and, what is especially important, psychologically. This separateness of the workers leads to periodic underloading and overloading of the workers, disturbance of the predetermined rhythm of product manufacture and the need for redistributing operations between workers. Because several workers communicate with one another via a single-channel transporter system when performing elements of the production cycle on conveyors with an unrestricted rhythm, it is difficult to determine the output of each worker, and delays can occur in the forward movement of articles for further processing.

Considering these shortcomings as well as the small dimensions and weight of the products being manufactured, an attempt was made to eliminate the shortcomings of the existing lines by developing a combined group-flowline organization for the glove making process. The basic unit of the new line is the sewing machine operator's workplace. It consists of an industrial tabletop of special configuration, such that the worker sits at a 45° angle in relation to the moving product. The workers are combined into groups. the members of which are closely associated between each other by their common task. The work is organized according to the batch principle, with an unrestricted rhythm. After performing her particular operation, a worker moves a finished batch a distance equivalent to her outstretched arm. This is enough for the batch to reach the workplace for the next operation. Thus the need for a conveyor line is eliminated when the labor is organized in this fashion. Direct multichannel communication of the workers with one another ensures technological and psychological interaction among the workers, which imparts discipline to their labor and introduces elements of visible competition, made possible by simultaneous sewing of the articles.

As time-and-motion studies of the work of sewing machine operators in the new work system showed, unwarranted breaks and departures from the workplaces disappeared entirely. The workers received a possibility for seeing one another in different positions without leaving their work, and for periodically exchanging various information that could supplement a lack of information at a particular workplace. A benevolent, friendly situation is created within the group.

These data show how much the psychological climate and psychological state are associated with labor organization and workplace design--that is, with satisfaction of the psychological requirements of ergonomics.

VI. THE CONTRIBUTION OF ERGONOMICS TO RESEARCH ON LABOR HYGIENE, PHYSIOLOGY AND PSYCHOLOGY

It has already been noted in the literature that the position of ergonomics among other sciences, and particularly its relationship to hygiene, has not been determined adequately yet (S. I. Gorshkov, A. V. Roshchin, 1974; S. I. Gorshkov, 1974). But the way things actually stand now, research in ergonomics often intersects research in physiology and psychology, and especially hygienic research in production. Because the domains of these sciences are not clearly delimited, there are difficulties in formally describing the obtained scientific information, in determining its membership to one science or another, particularly from the standpoint of Universal Decimal Classification indices. To make matters worse, we often hear it said that ergonomics is the science of sciences, one called upon to synthesize the achievements of economics, hygiene, physiology and psychology (K. K. Platonov, 1973). The same point of view is stated by (Zh. Sherrer) in his book "Fiziologiya truda, ergonomika" [Labor Physiology, Ergonomics]. A number of authors define ergonomics as a universal science of labor in general. Thus in his foreword to "Ergonomika" [Ergonomics] written by Polish authors, V. Venda writes that there is the "widespread opinion that ergonomics is the sum of a number of sciences of labor...." Other authors, for example (V. T. Singl'ton) in his "Vvedeniye v ergonomiku" [Introduction to Ergonomics] and M. de Monmollin in his book "Man and Machine Systems," reduce ergonomics to general labor technology or to general communications technology in a "man-machine" system.

Of course, such fundamental differences in the definition of the essence of ergonomics cannot promote success in its application; on the contrary, they can be a reason for mistrusting its possibilities. Such is the position, for example of hygienists, who believe that such broad interpretation of ergonomics diminishes the role of hygiene and increases the danger of competition in solving the age-old problems of hygiene.

In this connection the time has come to arrive at a more-objective definition of the positions of ergonomics and its mutual relationships with other sciences with which it must maintain contact--labor psychology and physiology, hygiene and engineering--having in mind the prospects for development of scientific research in particular. In this case we need to account for the present ideas of scientific theory on the criteria that may be used to objectively describe the role and place of both hygiene on one hand and ergonomics and labor physiology and psychology on the other within the system of sciences.

In scientific theory today, B. M. Kedrov has proposed three such criteria which he called cementation, pivotation and fundamentation. Cementation is defined as the possibility a certain science has for uniting, and cementing about itself--that is, binding--associated scientific disciplines for solution of certain problems. Pivotation, or vertelization, is defined as the capability a certain science has for introducing itself into a system of sciences examining a certain problem through gradual emersion into it. Fundamentation is defined as how well grounded the scientific premises of a certain science are by fundamental research methods, particularly from the standpoint of methodology and their mathematical support.

If we examine ergonomics from the standpoint of these criteria, we can gain an idea of its objective position within the system of sciences and of the way it interacts with hygiene, physiology and labor psychology.

An analysis would show that cementation is expressed to the greatest degree in hygiene and in ergonomics. Both of these sciences cement many associated sciences about themselves for solution of their problems.

Thus ergonomics is in a close relationship with engineering, hygiene, physiology and labor psychology. It cements these sciences of human labor, which is studied by them from their own unique positions. Ergonomics is unique in that it studies the correspondence of the design of production equipment and workplace organization to human anatomical, physiological and psychological features. Hygienic, physiological and psychological requirements on production equipment and on workplace organization, which are formalized today as state standards, have been developed as the criteria of this ergonomic correspondence. In this case ergonomics views this correspondence as the most important and mandatory principle of designing production equipment and organizing workplaces, violation of which would immediately cause difficulties in using equipment and workplaces, or make such use impossible without harmful consequences to labor productivity or even the health of laborers.

Thus for example there are entirely obvious consequences to violating the correspondence of certain dimensions of production equipment to anthropometric dimensions of the human body, and of the design features of equipment to the strength and speed possibilities of man; nevertheless, such incorrespondence is in fact encountered today. Also entirely obvious are the consequences of failing to meet hygienic requirements on the design of production equipment, which manifest themselves when due to design shortcomings the equipment becomes a source of intense production noise, excessive vibration, release of toxic gases and dust, and so on.

Protruding corners and levers, sharp edges, awkward composition and unattractive colors of equipment are sources of negative emotions and reduced performance, and hence we can understand the need for designers to create equipment having an appearance which would be the source of positive emotions.

Thus to solve its own problems, ergonomics cements about itself hygiene, labor physiology and psychology, and engineering--that is, all sciences which can provide concrete material that would permit us to comply with the principle of correspondence in the design of production equipment and in the organization of workplaces.

As a science, ergonomics also fully satisfies the requirements of the pivotation or vertelization criterion. Its fundamental principle--mandatory correspondence of the design of production equipment and the organization of workplaces to human anatomical, physiological and psychological characteristics--assumed concrete forms in different stages of man's historical development, though always remaining the main principle behind the structure of the implements of labor. Historical sciences, archeology in particular, indicate that the history of the mutual relationships between man and equipment has been characterized by growing complexity of technology until the time of the scientific-technical revolution of the 20th century.

In all of the stages of development of the mutual relationships between man and equipment, the principle of correspondence has always been decisive to optimizing these mutual relationships. Stone, bronze or iron tools were always made in accordance with this principle to fit the human hand using them. Correspondence was determined quite simply by fitting the tools to the hand, and if this correspondence was not satisfied, the tool was made to fit by the tool's possessor. The principle of correspondence operated spontaneously but inevitably in these cases. As machines were invented and as their complexity grew, and as computers and control consoles were introduced, the assistance of ergonomics in attaining this correspondence became more important. The design of production equipment had to evaluated in relation to the hygienic, physiological and psychological requirements of ergonomics indicated above.

It is evident from this that ergonomics reflects all of the historic stages in the nature of the mutual relationships between man and equipment. It made them more efficient, and it made labor easier and less detrimental to health, transforming it into a source of joy and inspiration. Thus ergonomics fits within the unbreakable chain of sciences--sociology, history, political economics, archeology, biology, physiology, psychology, hygiene and engineering, gradually deepening the process of cognition of the essence of the mutual relationships between man and technology, going as far as now permitting us to predict these mutual relationships in the future. Consequently ergonomics is in full correspondence with the requirements of the second criterion of scientific theory--pivotation.

As far as the fundamentation criterion is concerned, its requirements were embodied within the structure of ergonomics at the very moment of its arisal. The analysis, made above, of the historical development of the mutual relationships between man and technology from the ergonomic aspect indicates that the dialectical method is at the basis of this development. This method is precisely what has provided the possibility for using archeological data to demonstrate the inseparable unity of man, technology, nature and society.

Studying human labor, ergonomics comes in close contact with labor physiology, and in recent years it has been implementing the process of mathematical fundamentation together with it. This process can be boiled down to the following order of mathematical treatment of data acquired by investigation of physiological state. It is based on the idea that physiological processes are subordinated to the mathematical theory of random functions. In view of this idea, physiological processes and production parameters may be classified in each moment in time as random variables, and the sum total of these random variables, obtained by analysis and organized into a table or, as mathematicians would say, into a matrix, may be represented as a discrete random function, the ordinates of which are the random variables found by measurement.

Special algorithms have been developed to process such a matrix:

1) the value of the current mathematical expectation $m(t)$, indicating change in the mean value of the physiological or hygienic parameter in the dynamics of the work day;

2) the mean of the mathematical expectation $m(n)$, which permits us to evaluate the physiological functions of a single subject for the work day on the average;

3) the current deviation characteristic $D(t)$, which describes the extent to which physiological or hygienic parameters deviate from the means within the dynamics of a shift;

4) the mean of the deviation characteristic $D(n)$, which indicates the degree to which a physiological parameter of a single individual varies relative to its mean (its mathematical expectation);

5) the current autocorrelation function $r(t_1,t_2)$, which determines the relationship between values of the parameter under analysis in different moments of time in the dynamics of the work day. In the opinion of R. M. Bayevskiy (1965), the more homogeneous the internal structure of a certain series of values of an analyzed function is, the more slowly the autocorrelation function attains zero and the greater is the stability of the process;

6) the coefficient of the current mutual correlation function, which establishes the mutual influence among analyzed functions in individual moments within the dynamics of the work day, calculated in relation to all observations made in the course of their synchronous examination.

Data are processed on the basis of these algorithms by computer. As a result of such processing we get an objective description of the correlation between different functions, a description of the significance of deviations in certain functions resulting from the influence of certain labor-associated effects, and an idea of how much these functions would be optimized when certain recommendations are introduced.

This sort of mathematical fundamentation is employed extensively in ergonomics: This attests to the great role of the fundamentation criterion in ergonomic research.

Thus in terms of all criteria of scientific theory, ergonomics can be characterized as a progressive science, one occupying progressive positions in the system of sciences. In addition to the tremendous importance of the object of study--the mutual relationship between man and technology from the standpoint of the correspondence of the design of production equipment and workplace organization to human anatomical, physiological and psychological characteristics, the criteria of scientific theory discussed above make ergonomics one of the most important sciences of modern times, solving fundamental problems of the scientific-technical revolution in cooperation with hygiene, physiology and labor psychology.

There are different points of view concerning the mutual relationships of ergonomics with other sciences. At the same time, integration of the sciences and assumption of an integrated approach to solution of practical problems are doubtlessly reflections of an obvious trend in modern scientific knowledge.

We devoted significant attention in our work to the psychophysiological problems of ergonomics, since it is precisely these aspects that are now acquiring priority significance in the analysis and synthesis of man-machine systems. However, we have not abstracted ourselves from many other problems arising in the study and creation of man-machine systems. The systems approach basically requires ergonomics to maintain contact with other sciences that enrich it with new ideas, methods and approaches, and generally promote its development. It should be emphasized that when we go on to the study of man-machine-environment systems in general, the need for systems analysis becomes obvious.

The properties of such systems are apparently not simply the sum of the properties of the components making them up. A system generates new properties. In this connection we face the important task of developing integral criteria which would permit us to evaluate the parameters of man-machine systems namely as systems.

We believe that the systems approach should play an important role in development of a unified theory of ergonomics and in solution of practical problems.

Implementation of ergonomic recommendations suggested for concrete production operations by the authors of this book has demonstrated their effectiveness, as is confirmed by normalization of working conditions andthe work posture, reduction of the difficulty and intensity of the work of drivers, control console operators, the operators of bridge cranes at tube-rolling mills, computer operators, sewing machine operators, pattern cutters, weavers and spinners at light industry enterprises. Other confirmations can be found in the awards earned in various competitions, certificates of participation and exhibitions, the medals and certificates for efficiency proposals, and the inventor's certificates received by the authors of the book, and their participation in the writing of ergonomic GOST's. All of this confirms the tremendous effectiveness of industrial ergonomics and its promises for the future.

BIBLIOGRAPHY

1. Abdikulov, A. A., "Effect of Work Posture on Arm Movement Precision," in "Voprosy gigiyeny truda i profzabolevaniy" [Problems of Labor Hygiene and Occupational Diseases], Karaganda, 1974, 300 pp.

2. Anokhin, P. K., "Biologiya i neyrofiziologiya uslovnogo refleksa" [Biology and Neurophysiology of the Conditioned Reflex], Moscow, Meditsina, 1968, 547 pp.

3. Anokhin, P. K., "Ocherki po fiziologii funktsional'nykh sistem" [Notes on the Physiology of Functional Systems], Moscow, Meditsina, 1975, 447 pp.

4. Bel'gol'skiy, B. N., Glikman, E. S., Chukmasova, G. T. et al., "Ergonomic Requirements on Workplace Organization in Metallurgy," SOTS. TRUD, No 7, 1970, pp 69-72.

5. Benevolenskaya, N. P., "Etyudy po ergonomike" [Essays on Ergonomics], Novosibirsk, Nauka, Siberian Division, 1977, 141 pp.

6. Bocharova, S. I., "Symbolic Information Processing in the Memory," in "Psikhologichesiye problemy pererabotki znakovoy informatsii" [Psychological Problems of Symbolic Information Processing], Moscow, Nauka, 1977, pp 140-142.

7. Vasil'yeva, A. V., "Ergonomic Problems of Control Consoles in Heavy Industry, in "Doklady na Vsesoyuznom soveshchanii 'Konstruirovaniye mekhanizmov i oborudovaniya s uchetom fiziologicheskikh i gigiyenicheskikh kriteriyev ergonomiki'" [Reports at the All-Union Conference "Design of Mechanisms and Equipment With Regard to the Physiological and Hygienic Criteria of Ergonomics"] Moscow, 1971, pp 55-62.

8. Vinogradov, M. I., "Fiziologiya trudovykh protsessov" [Physiology of Labor Processes], 2d Edition, Moscow, Meditsina, 1966, 367 pp.

9. Volkova, I. M., "The EEG Correlates of the Effectiveness of Mental Activity," in "Materialy XXV Vsesoyuznogo soveshchaniya po problemam vysshey nervnoy deyatel'nosti" [Proceedings of the 25th All-Union Conference on Problems of Higher Nervous Activity], 2d Edition, Moscow, Nauka, 1977, pp 26-267.

10. Volkova, I. M., Gorshkov, S. I., and Kulumbetov, B. M., "Informational Interaction in the 'Man-Machine' System," in "Gigiyena truda v khimicheskoy promyshlennosti" [Labor Hygiene in Chemical Industry], Volgograd, 1975, pp 115-122.

11. Volkova, I. M., and Kulumbetov, B. M., "Electrophysiological Correlates of 'Psychological Readiness'," in "Materialy VII Vsesoyuznoy konferentsii po elektrofiziologii tsentral'noy nervnoy sistemy" [Proceedings of the Seventh All-Union Conference on Electrophysiology of the Central Nervous System], Kaunas, KMI, 1976, pp 85-87.

12. Volkova, I. M., and Kulumbetov, B. M., "Informational Interaction in a 'Man-Machine' System," in "Problemy inzhenernoy psikhologii i ergonomiki" [Problems of Engineering Psychology and Ergonomics], 2d Edition, Moscow, VNIITE, pp 211-213.

13. Goncharov, I. A., "Modernization of the PVG-8-2-0 Press to Improve Working Conditions," KOZHEV.-OBUVN. PROM-T', No 12, 1973, pp 34-35.

14. Gorshkov, S. I., "The Means of Perceiving Low Frequency Ultrasound," GIG. I SAN., No 1, 1969, pp 15-21.

15. Gorshkov, S. I., Volkov, I. M., and Kulumbetov, B. M., "Physiological Grounds for Using Warning Signal Systems at Workplaces in Textile Industry," in "Gigiyena truda na predpriyatiyakh Moskvy" [Labor Hygiene at Moscow Enterprises], Moscow, 1974, pp 41-45.

16. Gorshkov, S. I., Volkova, I. M., and Kulumbetov, B. M., "The Role of Supplementary Afferentation in Activation of Motor Reactions and Acceleration of Information Retrieval," in "Materialy sektsionnykh zasedaniy XXIV Vsesoyuznogo soveshchaniya po problemam vysshey nervnoy deyatel'nosti" [Proceedings of Section Meetings of the 24th All-Union Conference on Problems of Higher Nervous Activity], Moscow-Leningrad, Nauka, 1974, pp 110-112.

17. Gorshkov, S. I., and Kalinina, N. P., "Ustraneniye neudobnoy rabochey pozy u pryadil'shchits i s"yemshchits" [Correction of the Uncomfortable Work Posture of Spinners and Strippers], Moscow, 1964, 23 pp.

18. Gorshkov, S. I., Kokhanova, N. A., and Mal'tseva, O. M., "Some Ergonomic Problems in Textile Industry," TEKSTIL'NAYA PROM., No 8, 1970, pp 8-12.

19. Gorshkov, S. I., Roshchin, A. V., "Hygienic and Physiological Requirements of Ergonomics," in "Doklady na Vsesoyuznom soveshchanii fiziologicheskikh i gigiyenicheskikh kriteriyev ergonomiki," Moscow, Izd-vo AN SSSR, 1971, pp 5-28.

20. Gorshkov, S. I., and Goncharov, I. A., "The Significance of Psychological Criteria in Ergonomic Studies," in "Problemy inzhenernoy psikhologii i ergonomiki," 2d Edition, Moscow, VNIITE, 1974, pp 221-222.

21. Gorshkov, S. I., and Roshchin, A. V., "Formulation of the Tasks of Ergonomics," in "Problemy inzhenernoy psikhologii i ergonomiki," 2d Edition, Moscow, VNIITE, 1974, pp 221-22.

22. Gorshkov, S. I., Zolina, Z. M., and Moykin, Yu. V., "Metodika issledovaniy v fiziologii truda" [Research Methods in Labor Physiology], Moscow, Izd-vo Meditsina, 1974, 311 pp.

23. Gorshkov, S. I., Goncharov, I. A., Azova, S. M. et al., "Hygienic Working Conditions in Glove Production," KOZHEV.-OBUVN. PROM., No 11, 1972, pp 13-15.

24. Gorshkov, S. I., Zavalishin, D., Zarakovskiy, D., et al., "The Present State of Ergonomics in the USSR and the Socioeconomic Effectiveness of Introducing Ergonomic Research," in "Metodicheskiye problemy ergonomiki. Mater. I Mezhdunar. konf. spetsialistov stran--chlenov SEV i SFRYu" [Methodological Problems of Ergonomics. Proceedings of the First International Conference of Specialists From the CEMA Countries and Yugoslavia], Moscow, VNIITE, 1972, pp 169-276.

25. Gumener, P. I., Glushkova, Ye. K., and Sapozhnikova, R. G., "Kharakteristika vliyaniya fizicheskoy nagruzki na organizm shkol'nika" [A Description of the Influence of Physiological Load on the Schoolchild's Body], Meditsina, 1967, 247 pp.

26. Gurfinkel', V. S., Kots, Ya. M. and Shik, M. L., "Regulyatsiya pozy cheloveka" [Regulation of Human Posture], Nauka, 1965, 256 pp.

27. Yelizarova, V. V., "Change in Some Physiological Indicators Depending on the Efficiency of the Standing Work Posture," GIG. TRUDA, No 4, 1979, pp 47-49.

28. Zhukov, Ye. K., "Ocherki po nervno-myshechnoy fiziologii" [Notes on Neuromuscular Physiology], Leningrad, Nauka, 1969, 179 pp.

29. Zhunda, S., "Study and Dissemination of Progressive Labor Methods by Means of the Resources of Motion Picture, Photographic and Acoustic Technology," in "Nauchnaya organizatsiya truda v tekstil'noy promyshlennosti (Sb. statey)" [Scientific Organization of Labor in Textile Industry (Collection of Articles)] Moscow, 1970, pp 76-79.

30. Zbarskaya, L. Yu., "Some Physiological Changes Occurring in Control Console Operators at Tube-Rolling Mills," GIG. I SAN., No 7, 1965, pp 33-38.

31. Zinchenko, V. P., and Virgilis, N. Yu., "Formirovaniye zritel'nogo obraza" [Formation of the Visual Image], Moscow, Izd-vo MGU, 1969, 106 pp.

32. Zinchenko, V. P., Munipov, V. M., and Smolyan, G. L., "Ergonomicheskiye osnovy organizatsii truda" [Ergonomic Principles of Labor Organization], Moscow, Ekonomika, 1974, 240 pp.

33. Zinchenko, V. P., and Munipov, V. M., "Classification of the Forms of Operator Activity," in "Psikhofiziologiya truda operatorov avtomatizirovannogo proizvodstva" [Psychophysiology of the Labor of Operators in Automated Production], Moscow, 1974, pp 25-29.

34. Zolina, Z. M., "Fiziologicheskiye osnovy ratsional'noy organizatsii truda na konveyere" [Physiological Principles of Efficient Organization of Labor at a Conveyor], Moscow, Meditsina, 1967, 332 pp.

35. Okhnyanskaya, L. G. (Editor), "Kliniko-fiziologicheskiye issledovaniya nervnoy sistemy pri professional'nykh zabolevaniyakh" [Clinical Physiological Investigations of the Nervous System in the Presence of Occupational Diseases], Moscow, Meditsina, 1967, 216 pp.

36. Kozlov, V. N., "Ergonomic Problems in Agricultural Technology," in "Doklady na Vsesoyuznom soveshchanii 'Konstruiravaniye mashin, mekhanizmov i oborudovaniya s uchetom fiziologicheskikh i gigiyenicheskikh kriteriyev ergonomiki'," Moscow, 1971, pp 101-108.

37. Kokorev, N. P., "Hygienic Evaluation of Production Processes and Equipment in Ferrous Metallurgy," in "Doklady na Vsesoyuznom soveshchanii 'Konstruiravaniye mashin, mekhanizmov i oborudovaniya s uchetom fiziologicheskikh i gigiyenicheskikh kriteriyev ergonomiki'," Moscow, 1971, pp 122-129.

38. Kokhanova, N. A., and Abdikulov, A., "An Experimental Testing Unit Used to Simulate the Work Posture and Labor of Machine Tool Operators," GIG. TRUDA, No 11, 1975, pp 45-46.

39. Kokhanova, N. A., and Barkhash, G. I., "Change in the Physiological State of Grinders Depending on the Nature of the Work and the Design Features of the Equipment," GIG. TRUDA, No 4, 1973, pp 43-45.

40. Kokhanova, N. A., and Barkhash, G. I., "Registration of the Number of Movements by Means of Pedometers," GIG. I SAN., No 9, 1972, pp 100-101.

41. Kokhanova, N. A., Yelizarova, V. V., and Abdikulov, A., "Ergonomics in Modern Forge Production," in "Problemy inzhenernoy psikhologii i ergonomiki," 2d Edition, Moscow, VNIITE, 1974, pp 242-244.

42. Kokhanova, N. A., and Yelizarova, V. V., "Change in State of Higher Nervous Activity During Work in the Presence of the Temperature Factor," in "Materialy sektsionnogo zasedaniya XXIV Vsesoyuznogo soveshchaniya po problemam vysshey nervnoy deyatel'nosti," Moscow, Nauka, 1974, pp 117-118.

43. Kedrov, B. M., "The Dialectical Pathway of Theoretical Synthesis of Modern Knowledge in Natural Science," in "Sintez sovremennogo nauchnogo znaniya" [Synthesis of Modern Scientific Knowledge], Moscow, Nauka, 1973, pp 9-16.

44. Kryukova, D. N., "Electromyographic Analysis of the Degree of Tiring of Human Posture-Maintaining Muscles Depending on the Shape of the Work Seat," GIG. TRUDA, No 4, 1977, pp 12-16.

45. Kudin, P., Lomov, B., and Mit'kin, A., "Perception of Elementary Rhythmical Compositions on a Plane," TEKHN. ESTETIKA, No 8, 1969, pp 10-11.

46. Kulak, I. A., "Psikhicheskiye i fiziologicheskiye funktsii organizma cheloveka i sistema NOT" [Mental and Physiological Functions of the Human Body and the Scientific Organization of Labor System], Minsk, Belorus', 1974, 256 pp.

47. Kurashvili, M. Ye., and Boyakhcheva, O. R., "Influence of Microclimate on Thermoregulation of Rolling-Press Operators in the Conditions of the Tube-Rolling Mill of the Rustavi Metallurgical Plant," in "Voprosy gigiyeny truda, professional'noy patologii i promyshlennoy toksikologii" [Problems of Labor Hygiene, Occupational Pathology and Industrial Toxicology], Tbilisi, 1966, pp 23-31.

48. Layz, G., and Vyunsh, B., "Parameters of Adapting Workplaces to Man," in "Psikhofiziologicheskiye i esteticheskiye osnovy NOT" [Psychophysiological and Esthetic Principles of Scientific Organization of Labor], Moscow, NIItruda, 1967, pp 323-341.

49. Levitov, N. D., "Psikhologiya truda" [Labor Psychology], Moscow, Meditsina, 1964, 215 pp.

50. Lomov, B. F., "Ergonomics and Scientific Organization of Labor," SOTS. TRUD, No 8, 1969, pp 113-118.

51. Medved', R. A., "Influence of High Frequency Intermittent Noise on the Central Nervous System and on the Hearing Organ of Workers in the Principal Occupations of Forge Production," TR. GOR'KOVSK. MED. IN-TA IM. S. M. KIROVA, No 23, 1968, pp 57-63.

52. Mit'kin, A. A., and Kossov, B. F., "The Route of Visual Perception and Some Ways of Its Organization," in "Problemy inzhenernoy psikhologii" [Problems of Engineering Psychology], Moscow, Nauka, 1967, pp 2-55.

53. Moykin, Yu. V., "Fiziologicheskiye osnovy nauchnoy organizatsii truda" [Physiological Principles of the Scientific Organization of Labor], Moscow, Meditsina, 1971, 128 pp.

54. Moykin, Yu. V., and Poberezhskaya, A. S., "Electromyographic Criteria of Tiring in the Presence of Static Forces," GIG. TRUDA, No 4, 1973, pp 17-20.

55. Moykin, Yu. V., Poberezhskaya, A. S., and Kryukova, D. N., "Experience in Making the Work Postures of Sewing Machine Operators More Efficient," GIG. TRUDA, No 7, 1971, pp 24-27.

56. Orlova, T. A., "Problema bor'by s shumom na promyshlennykh predpriyatiyakh" [Noise Control at Industrial Enterprises], Moscow, Meditsina, 1965, 208 pp.

57. "Osnovnyye trebovaniya nauchnoy organizatsii truda pri proyektirovanii predpriyatiy, tekhnologicheskikh protsessov i oborudovaniya" [Principal Requirements of Scientific Organization of Labor Associated With the Planning of Enterprises, Production Processes and Equipment], Moscow, 1967, 197 pp.

58. Person, R. S., "Elektromiografiya v issledovaniyakh cheloveka" [Electromyography in Research on Man], Moscow, Nauka, 1969, 231 pp.

59. Piskun, L., "Future Developments of the Plowing Tractor," TEKHNICHESKAYA ESTETIKA, No 2, 1972, pp 2-4.

60. Rose, N. A., "Psikhomotorika vzroslogo cheloveka" [Psychomotor Functions of the Adult Man], Leningrad, Izd-vo LGU, 1970, 128 pp.

61. Sidorov, O. A., "Fiziologicheskiye faktory cheloveka, opredelyayushchiye kompanovku posta upravleniya mashinoy" [Human Physiological Factors Determining the Layout of a Machine Control Post], Moscow, Oborongiz, 1962, 117 pp.

62. Strokina, A. N., "Anatomical Problems of Work Seat Design," TEKHN. ESTETIKA, No 11, 1979, pp 13-18.

63. Strokina, A., Plyushkine, I., "Anatomical and Physiological Grounds of Some Angular Parameters of the Work Seat," TEKHN. ESTETIKA, No 7, 1972, pp 12-13.

64. Uflyand, Yu. M., "Fiziologiya dvigatel'nogo apparata cheloveka" [Physiology of Human Locomotor Apparatus], Leningrad, Meditsina, 1965, 363 pp.

65. Fuksman, A. Yu., and Gryzlova, T. A., "Organizatsionnyy rezhim raboty potokov so svobodnym ritmom" [Organization of Work on Flow Lines With an Unrestricted Rhythm], Moscow, Legkaya industriya, 1972, 126 pp.

66. Chernyshev, A. N., "Ergonomika v poligrafii" [Ergonomics in Polygraphy], Moscow, Kniga, 1969, 168 pp.

67. Chukmasova, G. T., Zbarskaya, V. Yu., Ripak, E. N., et al., "Hygiene and Labor Physiology in Tube Rolling Mills," in "Gigiyena, fiziologiya truda i profpatologiya v sovremennom metallurgicheskom proizvodstve i gornorudnoy promyshlennosti" [Hygiene, Labor Physiology and Occupational Pathology in Modern Metallurgical Production and Mining Industry], Kiev, 1970, pp 21-24.

68. Shalyutin, S. M., "Cybernetics and the Sphere of Its Application," in "Filosofskiye voprosy kibernetiki" [Philosophical Problems of Cybernetics], Moscow, Sotsekgiz, 1961, pp 3-20.

69. Shelyakhovskaya, N. K., "The Temporary Mental Starting State in the Labor of Student Turners at a Vocational-Technical School," Dissertation, Moscow, 1965, 21 pp.

70. Shirokov, Yu. G., Silant'yev, V. P., and Zinina, S. A., "Tensometric Investigation of the Loads Experienced by the Hands of Motor Vehicle Tire Assemblers," GIG. TRUDA, No 12, 1977, pp 53-57.

71. Shumilina, A. I., "Experimental Analysis of Formation of Systemic Associations in the Cortex and in Subcortical Formations During Development of Conditioned Responses," in "Sovremennyye problemy fiziologii i patologii nervnoy sistemy" [Modern Problems of Nervous System Physiology and Pathology], Moscow, Meditsina, 1965, pp 240-255.

72. Shumilina, A. I., "Neurophysiological Analysis of the Systemic Organization of the Conditioned Reflex," in "Kiberneticheskiye aspekty v izuchenii raboty mozga" [Cybernetic Aspects in Research on the Work of the Brain], Moscow, Nauka, 1970, pp 47-62.

73. Venda, V. F. (Editor), "Ergonomika. Problemy prisposobleniya usloviy truda k cheloveku" [Ergonomics. Problems of Adapting Working Conditions to Man], translated from Polish, Moscow, Mir, 1971, 421 pp.

74. Akerblom, B., "Anatomic and Physiologic Basis for the Construction of Seats," ERGONOMICS, Vol 12, 1969, pp 120-131.

75. Coupeau, L., and Besancon, K., "Industrie siderurgique. Un aspect de l'evolution des risques an laminage," ARCH. MAL. PROF MED. TRAV., Vol 28, 1967, pp 164-166.

76. De Vries, H. A., "Method for Evaluation of Muscle Fatigue and Endurance From Electromyographic Fatigue Curves," AM. J. PHYS. MED., Vol 47, 1968, pp 125-135.

77. Faverge, J. M., Leplat, J., and Guique, S. B., "Przystosowanie maszyny di czlowieka," Warsaw, 1963, 216 pp.

78. Grandjean, E., "Physiologische Arbeitsgestaltung. Leit Fadan der Ergonomie," Thun and Munich, Ott, 1967, 268 pp.

79. Grandjean, E., and Burandt, U., "Untersuchungen uber das Sitzverhalten Buroangestellten und uber die Auswirkungen verschiedenartiger sitzprofile," ERGONOMICS, Vol 12, 1969, pp 338-348.

80. Hacker, W., "Some Psychological Aspects of Establishing 'Human-Centered' Man-Machine Systems," in "20th International Congress of Psychology," Tokyo, 1972.

81. Heider, M., and Groll, E., "Belastungsunterschiede bei freier Arbeit und Banderbeit," Z. PRAVENTIMED, Vol 11, 1966, pp 303-310.

82. Mandel, A. C., "Work-Chair With Tilting Seat," ERGONOMICS, Vol 19, 1976, pp 157-164.

83. (Monmollin, M. de) Monmollen Moris de., "Sistemy chelovek i mashina" [Man and Machine Systems], translated from French, Moscow, Mir, 1973, 255 pp.

84. Murrell, K. F. H., "Ergonomics . Man in His Working Environment," London, Chapman and Hall, 1965 496 pp.

85. Okon, J., "Paluszkiewica. Psychologia inzynieryjna," Warsaw, 1966, 306 pp.

86. (Rosner, J.) Rozner, Yan., "Adapting Working Conditions to Man," in "Ergonomika" [Ergonomics], Moscow, Mir, 1971, pp 25-30.

87. Schneider, H. T., and Zippert, H., "Das Sitzproblem in funktionell-anatomischer Sicht., MED. KLIN., Vol 27, 1961, pp 1164-1168.

88. Schoberth, H., "Das Sitzmobel am Arbeitsplatz, DTSCH. GESELLSCH. UNFALLHEIL., Vol 4, 1965, pp 340-446.

89. Von W. Schultetus, "Die Ergonomie als Hilfsmittel zur Gestaltung von Produkten fur den industriellen Gebrauch," ERGONOMICS, Vol 17, 1974, pp 515-527.

90. Tichauer, E. R., "Ergonomics: The State of the Art," AM. INDUST. HYG. ASS. J., Vol 28, 1967, pp 105-108.

91. (Woodson, W., Conover, D.) Vudson, U., and Konover, D., "Spravochnik po inzhenernoy psikhologi dlya inzhenerov i khudozhnikov-konstruktorov" [Handbook of Engineering Psychology for Engineers and Designers], translated from English, Moscow, Mir, 1968, 518 pp.

92. "Kellermann, F. Th., van Wely, P. A., and Willems, P. J. (Editors), "Vademecum Ergonomics in Industry," Eindhoven, Centrex, 1963, 92 pp.

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