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TOSHKENT DAVLAT TRANSPORT UNIVERSITETI
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Modeling the neutral state of the “human-operator” system

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Abstract: In this article, a physical and mathematical model of the external forces involved in reducing the static loading of the body of workers and people using video terminals or computer monitors in a sitting position was developed. A theoretical analysis was conducted on the basis of the developed models, the equations of the balance conditions of the forces in the physical model made it possible to create a mathematical model. Through the analysis of the created mathematical model, the conditions for the minimum contraction force of the members of the human locomotor apparatus, that is, the muscles participating in the maintenance of the posture of the workers and people during the work process in the sitting position, were determined. The conditions obtained on the basis of the defined mathematical model are used in the development of the model of the course layout, which allows to ensure the "neutral position" of the human body, and to calculate the values of the project parameters.
Keywords: musculoskeletal system, sitting position, muscles, forces, weightlessness, neutral position, human-operator system, chair

1. Introduction

One of the important characteristics of workers and people who work using video terminals or computer monitors is that they work mostly in a sitting position during their daily work (day) shift. Reducing the static load of the body in a sitting position depends on the external forces acting on the musculoskeletal system. External forces are balanced by internal muscle forces in maintaining a neutral body position in a sitting position. Therefore, it is very important to develop and substantiate the physical and mathematical model of the external forces involved in maintaining the neutral body position of a person in a sitting position [1,2].

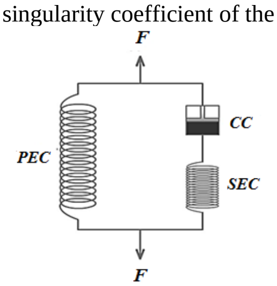
It is known that the activation of the organs of the musculoskeletal system of the human body, that is, the muscles, occurs in different conditions. Muscles performing movement in body parts perform "dynamic" work. If the muscles of the musculoskeletal system are activated isometrically, that is, their length is constant during force generation, the members of the musculoskeletal system do not move and mechanical work is not performed. The activity of the muscles of the locomotor apparatus in this mode has an important aspect, although the muscles generate forces that resist external mechanical influences, but these forces serve to keep the body in a sitting, bent position. In such a "static" state, activated muscles do not perform mechanical work, but do not stop using energy for a moment [3]. The mechanical force generated by human muscles depends on their various physiological, mechanical, and morphological properties.

2. Methods and materials

Ishlab chiqarish muhiti va mehnat jarayoni (fizik, The mechanical model of the muscle, as a rule, completely corresponds to the three-element (component) universal (standard) Kelvin model (Pictire. 1). Muscle fibers are distinguished by their high viscosity, so in the model they are shown in the form of a damper. Viscous fluid deformation rate and stress level are characterized by a direct, proportional relationship. The relationship between the rate of deformation and the level of stress is described by the coefficient of viscous damping [4].

This element in the model is called the contractile component (CC). The second component of the model is the fascia surrounding the muscle and the connective tissue formations surrounding the muscle bundles, muscle fibers, myofibrils, etc. have elastic properties.

This component is called the parallel elastic component (PEC) because it is located parallel to the muscle fibers. In the model, PEC is imitated in the form of a spring representing a nonlinear relationship between force and stretch, and the law of connection between force and stretch depends on the coefficient of uniformity (elasticity) of the muscle fiber. The third component of the model is share. This component is also dominated by elastic properties, but the coefficient of elasticity (elasticity) of this component is large compared to the parallel elastic component. Muscle fibers are connected to tendons, that is, this component is located sequentially with respect to the contractile component, so it is called the sequential elastic component (SEC). In the model, SEC is simulated in the form of a spring representing a nonlinear connection between force and elongation, and the law of force-elongation coupling depends on the singularity coefficient of the tendon [4].



Picture 1. A three-component model of muscle

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The force generated when the musculoskeletal system is activated, the reaction force generated by the muscle is expressed by the following formula for the universal (standard) Kelvin model [4]:

$$F + \frac{c}{k_{cc}} \cdot \frac{dF}{dt} = k_{sec} \cdot \left[x + \frac{c}{k_{sec}} \cdot \left(1 + \frac{k_{sec}}{k_{cc}}\right) \cdot \frac{dx}{dt}\right], \quad (1)$$

in this F – initial force, N; c – viscous damper coefficient N/m; k_{cc} – coefficient of unity of the contracting (contractile) component, N/m; k_{sec} – unit of the successive elastic component (SEC), N/m; x – initial muscle length, m;

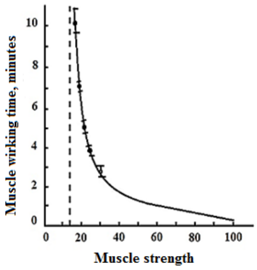
The bonds in this (1) formula are as time constants $\tau_\varepsilon = \frac{c}{k_{cc}}$ and $\tau_\sigma = \left(\frac{c}{k_{sec}}\right) \cdot \left(1 + \frac{k_n}{k_{cc}}\right) = c \cdot \left(\frac{1}{k_{sec}} + \frac{1}{k_{cc}}\right)$ with set to, the output formula:

$$F + \tau_\varepsilon \frac{dF}{dt} = k_\varepsilon \cdot \left[x + \tau_\sigma \cdot \frac{dx}{dt}\right] \quad (2)$$

This equation is A. Hill's equation is that the rate of contraction of a muscle by force of opacugaru represents a bond, and as seen from the equation, muscle strength changes slowly through τ_ε the time constant to a new level.

A large number of biophysical studies have shown that the kypa, the contracting (contractile) component (CC) of the ***c*** squash dempfer coefficient is parallel to the elastic component (PEC), the successive elastic component (SEC) of the ***k*** bicrlik (elastic) coefficients of the muscle and tendon fibers of the temperature *T*, the contraction rate of *v* and the length ***x*** of the muscle $c=f\,(T,v,x)$ and $k_{cc,sec} = f\,(T,v,x)$. In addition, an increase in the time of loading the muscles leads to a decrease in the strength that formed them.

As described in the Romert Hyperbola (Picture. 2) (data shown as the average value of the standard deviation (SD = standard deviation)), skeletal muscles can withstand sufficiently strong static loads only for a limited time. The abssissa in this graph is given the maximum mechanical force (in percent) that is generated when the muscles contract or tense, while the ordinate ykuga is given the time to be in a contracted or tense position for the muscles to generate strength. For a load with a maximum value of less than 1500, the muscle fatigue time is much greater (not indicated on the graph), but still not infinite.



Picture 2. Muscle static mode force curve-Romert Hyperbola

Muscle fatigue is caused by metabolic changes in the muscles, deterioration of the mechanisms of its activation (braking, fatigue). Strength can be reduced due to several metabolic factors that make it difficult for muscle tendons to bond and separate. These factors are caused by the formation of lactic acid in the fibers, an increase in phosphate levels and a decrease in creatine phosphate.

Increasing blood pressure within a muscle to higher than maximum pressure limits blood flow, which reduces the amount of oxygen flow to the muscle (i.e. leads to muscle ischemia), and also slows down the process of releasing metabolic products from the muscle.

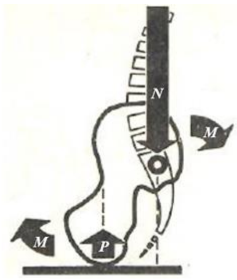
According to brugerr's theory, most diseases of the musculoskeletal system are not direct diseases associated with it, but the protection of the Central and peripheral nervous system [5]. These protective mechanisms are activated when there is not enough load on the structures of the musculoskeletal system. Such a constantly working non-rational load disrupts the potential for the restoration of" overloaded " structures, and only functional disorders develop at the initial stage. Subsequently, structural changes may develop if they are not eliminated. In the medical literature, it is noted that computer users have long-term static load syndrome, which can lead to curvature of the spine, hands, neck, back pain and other diseases, issues of the influence of static disorders of the human musculoskeletal system on the biomechanical properties of muscles are raised [6].

Currently, the study of these problems continues in two directions: the design of the workplace in which the computer is installed, and then its development in terms of ergonomic feasibility, as well as the study of a complex of external and internal reasons, the origin of various unpleasant situations during prolonged work at the computer, as well as issues of violation of the spatial.

According to a number of experts [7, 8, 9], if working conditions require maintaining the static state of the upper body for a long time, it is necessary to take into account the load on the muscle groups that provide it. G.G. According to demirchoglyan [6], working too much in front of the computer can cause neck pain, back pain, osteochondrosis and various other diseases, so that the chair for workers in front of the computer should be equipped with shovels, lower back and armrests and adjusted in a comfortable position. No matter how comfortable it is for a person to sit in front of a computer, the "working day" in front of the screen should not exceed six hours, and at the same time, breaks and short-term physical education exercises should be performed every two hours. Consideration of the "sitting" biomechanics of the posture of work directly depends on the location of the column of the spine, the determination of the mechanism for creating a mechanical load on the discs between the spine when deviating from the rational position when working at a computer [8].

Rock S.M. [5] in his opinion, the configuration in a sitting position is characterized by balanced physiological curves of the column of the spine, the axis of the spine is decisive as the support of the human body. According to the author, three wheels form a biomechanical basis for the optimal configuration of the shovel and lumbar part.

In the correct working position, the load on the front and rear parts of the discs between the spine is approximately the same [10].



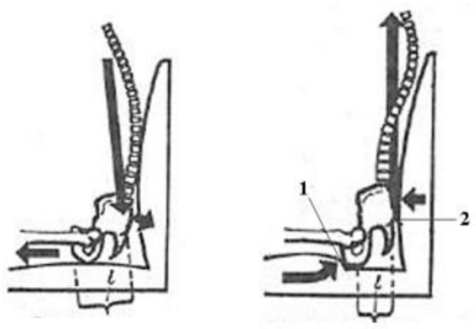
Picture 3. Formation of torque *M* in a sitting position

M- torque, ***N***- elasticity strength, ***P***- base strength reaction

A number of authors [9] tend to consider the movements of the column of the spine as deformations of a solid, in which the force of elasticity ***N*** occurs, arising from the electromagnetic interaction between atoms and molecules of substances, seeking to restore the previous shape of the body, and contradicting the force of pressure on the ***P*** support of the spinal column.

In users of videoterminals or computer monitors, the position of tilting the body forward is most often observed, in this position they bend forward, and the upper part of the body, bending the center of gravity, brings the eyes closer to the reference surface on the monitor. In a sitting position without a backrest, the weight that falls on the lumbar region increases due to the forces arising from the weight of the body in the upper parts. As a result, the moment of a person's transformation into the pelvis is affected, which, when the muscles relax, leads to the rotation of the pelvis, moving forward and turning the body back. In this position, the forces acting on the lumbar region increase, which leads to a load of discs between the spine. The effect of this moment can be neutralized to some extent by means of a backrest [10].

Depending on the results of the video chronometry [2], video terminals or computer monitors can withstand 85-90% of the day (daytime) time zone change, while their angle of inclination should not exceed 20^0.



a) b)

Picture 4. Impact of seat profile on posture

a - flat seat (there is a slip); b - recessed seat (no slip); 1-base pad; 2-swing.

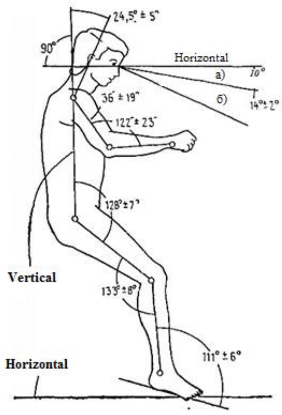
In a flat seat course, the weight of the upper body creates a rotational moment that affects the pelvis, which causes the torso to move forward and the spine column to bend; this position is uncomfortable and often leads to injury or pain in the lower back and pelvis. The seat has a base cushion course, reducing the forward movement of the torso. The backrest in the lumbar area holds the pelvis in an anatomically correct position [10].

Studying the dynamics of the working position while sitting with the body bent back, it should be noted that the weight of the upper body parts affects the spine as a result of the fact that during labor activity, users of videoterminals or computer monitors do not lean on the back of their course.

Video terminals or computer monitors can display information on the screen about what is happening to the disk, which moves along the disk in the direction opposite to the direction of rotation of the disk, which leads to an increase in the mass of the disk.when a torque occurs on the axis of rotation, its braking occurs, and when it occurs, braking occurs on the axis of rotation. These muscles are located in the area of the intervertebral disc, that is, between the nuclei of the spinal column, and therefore their strength is less than gravity. Thus, when the body rotates relative to the axis of rotation (axis of rotation), the angle of inclination of the axis of rotation relative to the axis of rotation is equal to the modulus of the abscissa of the center of mass, as a result of which the angle of inclination of the axis of rotation becomes equal to the angle of inclination of the axis of rotation.

It is known that a change in the state of a person's posture (lying, standing, sitting, bent, squatting, etc.) leads to a change in the direction of the vectors of the gravitational forces (gravity forces) of the biosensors of the musculoskeletal apparatus. The result is also a change in the load on the muscles, which are activated in ensuring a certain position of the musculoskeletal system. Regardless of the state of the torso in the inertial counting system, the gravitational forces of the biozvenos of the musculoskeletal apparatus are always involved, and they are considered external forces of influence. Therefore, in any posture, a certain group of muscles of the musculoskeletal apparatus of a person is influenced by statistical loading. The greater the weight of the biosvenos of the musculoskeletal apparatus, that is, the surface on which they receive the force of gravity, the less the static force that arises from the isometric contraction of the muscles.

In the case of “weightlessness”, which leads to a sharp decrease in the effect of the forces of Biozvenolar gravity, the perceived form of the human torso, the “neutral position” of the torso clearly demonstrates this. The shape that a person receives in a state of "weightlessness" (Picture 5) resembles the 900 turn position of The Shape of the torso that a person swimming in water receives, the reason is that in the water the gravitational forces acting on the muscles of a person are sharply reduced, and the muscles switch to a mode in the form of a “neutral position”.



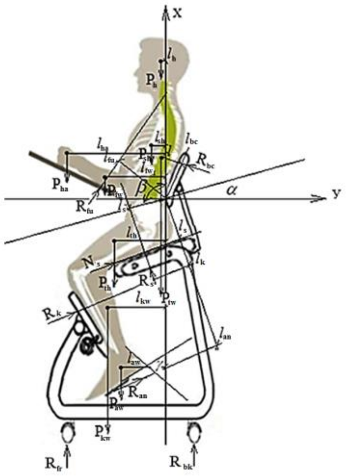
Picture 5. The body's acceptance of a “neutral position” in balance

a) g=9,8 m/s^2 when the direction of vision; б) g=0 when the direction of vision

This condition is also known as a condition that helps define contours called "Light chairs". This" neutral " condition may be a condition in which there is a minimum muscle strength that affects parts of the body that are in balance [11].

Reducing the load on the muscles of the human musculoskeletal system associated with the state of the body allows you to dramatically reduce the static load on the posture of users of videoterminals or computer monitors in a sitting position. That is why it is necessary to ensure the balance of the reaction forces of the gravitational and course parts of the biozvenos of the human body musculoskeletal apparatus sitting on the stool in order to bring the state of the torso, which users of videoterminals or computer monitors receive for a long time during the daily work (day) shift, closer to the "neutral state". This can be ensured by analyzing the equilibrium conditions of the reaction forces (which provide the state of the torso) of the individual base parts of the course of their resistance, that is, in the opposite direction to the gravitational forces of their biosvenos in the sitting position in the course of users of videoterminals or computer monitors. Therefore, a physical (statistical) model has been developed that allows users of videoterminals or computer monitors to carry out a theoretical analysis of the conditions of ensuring that their sitting position is close to a "neutral position" and its mathematical model has been created.

In the following view, a physical model of the "man-operator" system was developed.



Picture 6. Physical model of the "human-operator" system

In the development of the physical model of the "human-operator" system, the following assumptions were made:

- the right and left parts of the human body, divided according to the saggital plane, have equal weight values;
- the values of the weights of the right leg and arm and the left leg and arm are equal;
- the internal friction forces of the joints of the biosensors of the musculoskeletal apparatus are not involved in maintaining or changing balance;
- the participation of the strength of the muscles of the musculoskeletal system in ensuring the "neutral position" pose of the human body has a minimum value or is close to zero;
- the change in the position of the human head does not form the tension of the muscles of the lower biosvenos of the musculoskeletal apparatus;
- in the "neutral position" pose, the coordinates of the Centers of gravity of the right and left biosvenos of a person do not change in relation to the counting point, axes and planes;

-individual parts of the chair and the work table are fully accepted for the weights of the biosvenos of the musculoskeletal system.

It is known that the mathematical model of the equilibrium condition of ensuring the neutral state of the "human-operator" posture while sitting at the human course is represented by the following equations:

$$\sum_{i=1}^{n} F_{xi} = 0 \quad \sum_{i=1}^{n} F_{yi} = 0 \quad \sum_{i=1}^{n} M_{oi} = 0 \qquad (3)$$

To determine the equilibrium conditions of the "human-operator" body based on the developed physical model, it is necessary to write the equation of forces acting on the horizontal (abssissa) axis in the form:

$$-P_h - P_{tw} - P_{sh} - P_{fw} - P_{ha} - P_{th} - P_{kw} - P_{aw} + R_{fu}\sin\alpha_{fu} + R_{bc}\sin\alpha_{bc} + N_s\sin\alpha_s + R_k\sin\alpha_k + R_s\cos\alpha_s + R_{an}\cos\alpha_{an} + R_{fr} + R_{bk} = 0, \qquad (4)$$

in this P_h – head weight strength, P_{tw} – thorax (chest) weight strength, P_{sh} – shoulder weight strength, P_{fw} – forearm weight strength,P_{ha} – hand weight strength, P_{th} – thigh weight strength,P_{kw} – knee weight strength, P_{aw} – ankle weight strength,R_{fu} – forearm underarm trigger reaction force, R_{bc} – backrest reaction force, N_s seat-human friction force, R_k – knee brace reaction force, R_s – seat reaction force, R_{an} – ankle awns spring heap reaction,R_{fr} – front base wheel reaction force, R_{bk} – back base wheel reaction force, N.

(4) from the formula, the conditions for the balance of the external forces of the "human-operator" in a sitting position on the course on the vertical plane are given.

The forearm underarm trigger reaction force, equal to or greater than the sum of the shoulder, forearm and hand weight forces, ensures that they are in balance without the participation of muscle forces, i.e.:

$$R_{fu} \geq (P_{sh} + P_{fw} + P_{ha})\cos\alpha_{fu} \qquad (5)$$

The resistance force of the seat reaction force of the stool is equal to or greater than the vertical organizer of the sum of the forces of the head, torso, thigh, calf and stem weight, sharply reduced the participation of muscle strength in ensuring their balance:

$$R_s \geq (P_h + P_{tw} + P_{th} + P_{kw} + P_{aw})\cos\alpha_{fu} \qquad (6)$$

The resistance force of the stool backrest is equal to or greater than the horizontal organizer of the sum of the weight forces of the head, torso, shoulder, forearm and palm provides a sharp decrease in the strength of the muscles involved in this posture:

$$R_{bc} \geq (P_h + P_{th} + P_{kw} + P_{fw} + P_{ha})\sin\alpha_c \qquad (7)$$

The sum of the reaction force of the knee brace and the resistance force of the seat to the glide of the torso does not require that the head, torso, thigh, calf and stem be equal to or greater than the sum of the weight forces, that the muscles involved in maintaining the posture are in a tense pull and contraction mode, that is,:

$$(R_k + N_s) \geq (P_h + P_{tw} + P_{th} + P_{kw} + P_{aw})\sin\alpha_s \qquad (8)$$

The deformation force of the spring stirrup, which compensates the weight force of the STEM and calf, is equal to or greater than the vertical organizer of the sum of the forces of the weights of the calf and the stem, sharply reduces the strength of the muscles that hold the position of the legs:

$$R_{an} \geq (P_{kw} + P_{aw})\cos\alpha_s \qquad (9)$$

The equilibrium formula of the forces acting in the direction perpendicular to the vertical (ordinate) axis in the physical model is expressed as follows:

$$-R_{bc}\cos\alpha_s + (R_k + N_s)\cos\alpha_s + R_{an}\cos\alpha_s = 0 \qquad (10)$$

(10) the formula expresses the conditions under which the balance of the "neutral position" sitting "human-operator" is provided in the horizontal plane.

The course of the reaction force of the knee brace, the strength of the seat's resistance to gliding on the torso, the sum of the deforming force of the spring stirrup armrest greater than or equal to the reaction force of the dispatcher provides a sharp reduction in the strength of the muscles involved in maintaining the posture:

$$R_k + N_s + R_{an} \geq R_{bc} \quad (11)$$

The moments of force acting on the posture of the" man-operator "in a sitting position in the chair of the “neutral position” are expressed as follows:

$$R_{an} \geq (P_h + P_{tw} + P_{th} + P_{kw} + P_{aw}) \quad (12)$$

The balance conditions of the torques are expressed by the balances of the clockwise and counterclockwise torques, and the fulfillment of these conditions requires the minimum values of the muscle forces involved in maintaining the body position of the “human-operator”:

$$-P_h \cdot l_h - P_{sh} \cdot l_{sh} - P_{tw} \cdot l_{tw} - P_{fw} \cdot l_{fw} - P_{ha} \cdot l_{ha} - P_{th} \cdot l_{th} - P_{kw} \cdot l_{kw} - P_{aw} \cdot l_{aw} - R_{bc} \cdot l_{bc} + R_{fu} \cdot l_{fu} - N_s \cdot l_s - R_k \cdot l_k + R_{an} \cdot l_{an} + R_{fr} \cdot l_{fr} + +R_{bk} \cdot l_{bk} = 0 \quad (13)$$

$$R_{fu} \cdot l_{fu} \geq P_{sh} \cdot l_{sh} + P_{fw} \cdot l_{fw} + P_{ha} \cdot l_{ha} + R_{bc} \cdot l_{bc} \quad (14)$$

$$P_{fr} \cdot l_{fr} \geq P_h \cdot l_h + P_{tw} \cdot l_{tw} + P_{kw} \cdot l_{kw} + P_{aw} \cdot l_{aw} + N_s \cdot l_s - R_k \cdot l_k + R_{an} \cdot l_{an} + R_{bk} \cdot l_{bk}$$

3. Conclusion

A theoretical analysis was conducted on the basis of the developed models, the equations of the balance conditions of the forces in the physical model made it possible to create a mathematical model. Through the analysis of the created mathematical model, the conditions for the minimum force of contraction of the muscles of the human locomotor apparatus involved in maintaining the body position during the work process while sitting were determined. The conditions obtained on the basis of the defined mathematical model are used in the development of the model of the course layout, which allows to ensure the “neutral position” of the human body, and to calculate the values of the project parameters.

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