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Biomechanical substantiation of mechanical impulse transfer mechanisms in the "athlete – sports equipment" system when performing moving actions in sports

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Purpose: *to investigate mechanical impulse transfer mechanisms in the* ***"****athlete – sports equipment****"*** *system when performing moving actions in sports.*

Material & Methods: *theoretical analysis and compilation of scientific and methodical literature and our own research results.*

Results: *mechanism of interaction of individual body biolink's in the performance of physical exercises is studied, the basis of which is the coordination of accelerations and decelerations of the body's biolink's movement and the sequence of their incorporation into the work, which is crucial for achieving the necessary speed of the working biolink of the athlete's body when exposed to the equipment.*

Conclusion: *mechanism of successive acceleration and successive braking of the body's biolink's in the final phase of motion ensures the transfer of the linear and rotational momentum from segment to segment, from the lower part of the body to the top and from the top to the shell, thereby informing him of the maximum speed.*

Keywords: *biomechanical, impulse, biolink, moving actions, sport.*

Introduction

In the studies of the technique of sports movements, a special place is occupied by studying the position and interaction of different body biolinks during physical exercise, since these components of the final motor effect greatly influence the dynamic structure of its organization [3; 5–7]. The dynamic structure of physical exercise includes the vector set of forces involved in solving the motor problem. The strength of the action depends directly on the traction of the muscles, i.e., the forces with which the individual muscles pull the bone levers. However, there is no one-to-one correspondence between the tension of a particular muscle and the strength of the action, since the changes in the joint angles change the working conditions of the muscles, in particular, the length of the arms of the muscular traction forces [5; 15]. It is also known that the resultant force of the athlete's impact on the equipment depends on the magnitude and direction of forces produced by each link [1; 2]. Consequently, the manifestation of the greatest effort in the optimal direction depends on the coordination of accelerations and decelerations of motion of different parts of the body and on the sequence of their incorporation into the work that is determining for achievement of necessary speed of a working link of a body of the sportsman or equipment. In the scientific and methodological literature this phenomenon is represented by the biomechanical principle of the transmission (transfer) of the impulse in the system of links [15, 20], practical implementation of which requires a " single-discipline" adaptation to each specific type of movements and moving movements, in particular.

The relationship of research with scientific programs, plans, themes

The work was carried out in accordance with the "Plan for research work of the National University of Physical Education and Sports of Ukraine for 2016–2020" on topic 2.32 "Technical training of qualified athletes based on the modeling of the rational motor structure of sports exercises" (state registration number 0114U001531).

The purpose of the research

To investigate mechanical impulse transfer mechanisms in the **"**athlete – sports equipment**"** system when performing moving actions in sports.

Material and Methods of the research

Research methods: theoretical analysis and generalization of scientific and methodological literature data and results of own research.

Results of the research and their discussion

We can distinguish three types of interaction of the body links depending on the purpose, which is solved by this movement [11; 13; 16; 17]:

1. If the task is to develop the maximum force, then all links act simultaneously, with the exception of "weak" links.

2. If the speed of the equipment or biolinks is important, the links act sequentially, each following is activated at the moment when the previous one reached the maximum speed.

3. If there is an effect of one or more links, the underlying links should be fixed and create a base (support) for the more effective operation of the overlying links.

The task of optimizing the addition of the forces of individual links is complicated by the fact that in the throwing the athlete must unite all these types of interaction of the body links in a certain sequence. First, he must inform the equipment of the maximum speed of departure, secondly, to accelerate the equipment, it is necessary to show maximum effort and, thirdly – throw is completed with one hand. Therefore, it is necessary that all three types of interaction of the links of the body be: in javelin throwing – 0,12–0,15 s, in shot put – 0,25–0,30 s (time of final effort).

Considering the sequence of inclusion in the work of different links, it is necessary to take into account that the athlete faces the task of using the strength of different links when the muscles that move these links, can reduced at such a rate that the force action on the accelerated masses is the maximum. The strongest body links are the most massive and, therefore, have greater inertia. Therefore, the movement must begin the powerful muscles of the pelvic region, and to finish – limb muscles [17].

At the basis of the transfer of a mechanical pulse along the kinematic chain lies the mechanism of sequential inclusion of the body links, which in the literature has several alternative names: principle of summation of internal forces [11], principle of serial organization of motion [14], principle of speed summation [18], principle (mechanism) of the muscular wave [1]. When implementing this mechanism, it is important to coordinate as accurately as possible the switching from one link of the kinematic chain to another. On the importance (degree of influence on the sporting result), this principle of organization of movement is equated with the principle of preliminary stretching of the muscle-tendon complex, Noting that it is especially important to apply this principle in the throw disciplines (javelin and a discus throw, shot put), as well as in the performance of percussion actions.

Movement begins with large and strong muscle groups of proximal segments that are located near the common center of the body mass. These muscles are predominantly with a fan-shaped arrangement of fibers, i.e., muscles with a large physiological diameter and possessing a great contraction force. The main task of these muscles is to communicate speed to the entire system of "athlete – a sports equipment", to overcome the inertia of the body of an athlete and a sports equipment [13]. The continuation of the movement (dispersal of the working link and equipment) provides, from the point of view of the manifestation of force, less strong but faster muscles of the upper limbs. Their task is not only to ensure the rapid movement of the body links, but also the sufficient accuracy of the performed movement. In these muscles, the number of fibers is less than in the more massive and strong muscles, which affects the force of contraction. Less and the number of muscle fibers innervated by one motor neuron. This means that the central nervous system can provide a more perfect control of the work of these muscles, increasing not only the speed of movement, but also the accuracy of the movement [12; 21].

The speed of the working link in the impacts in equipment throws is the result of the summation of the velocities of the individual links of the body-legs, trunk and arms. The question arises as to how the velocity vectors of the individual body links must be combined in time, so that the velocities of the final link and the equipment are maximal.

Theoretically, there are two ways of interacting the body links to achieve the maximum speed of the final link. The first is characterized by such organization of movements, in which the maximum speeds of individual links coincide in time (Fig. 1).

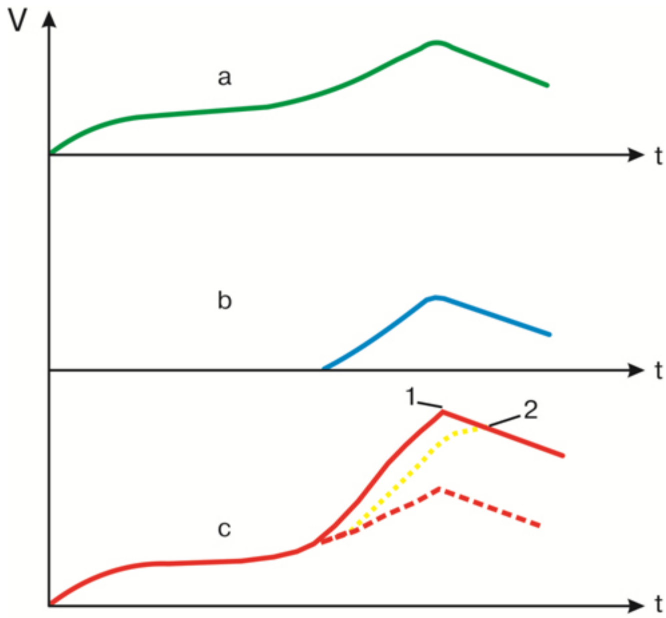

Fig. 1. Scheme of a combination of the speeds of separate body links [26]:
a – torso speed; b – arm speed; c – equipment speed. 1 –speed of the equipment is maximum, if the maxima of the speeds of the links coincide in time; 2 – the mismatch of the speed maxima in time of the torso and shoulder reduces the speed of the equipment.

In the second method, the body links are gradually accelerated from the bottom up, that is, each subsequent (overlying) link starts its movement when the speed of the previous one reaches a certain value. Schematically such interaction of links is presented in Fig. 2.

From the point of view of biomechanics, the most rational option is (a) – the overlying link is activated at the moment when the speed of the underlying link reaches a possible maximum. There is an effective accumulation of energy of motion. Option (b) – late, overlying bioscience is turned on when the speed of the underlying biofeedback began to decline, part of the energy has already dissipated; (c) ahead, the overlying bioscience is switched on prematurely, the athlete spends energy on maintaining the speed of movement.

The aforementioned variants of the interaction of the body's

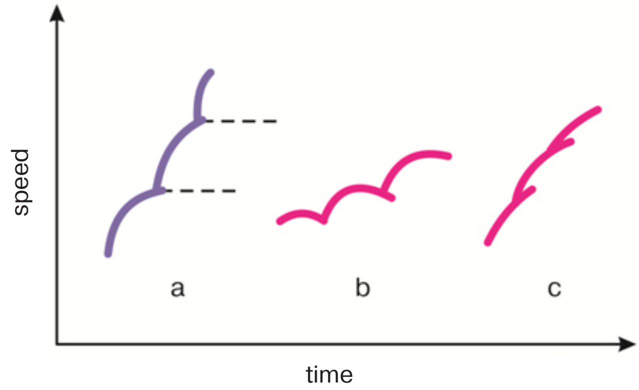

Fig. 2. Variants of a speeds combination individual body's biolinks [5]:
a – timely; b – late; c– ahead.

biolinks are rational from the point of view of biomechanics. But with their practical implementation, we must reckon with some biomechanical phenomena. First, each muscle has not only its maximum power and power capabilities, but also mechanical properties, for example, elasticity. Secondly, the body's biolinks differ in their mass-inertial characteristics. Even under the condition that the same moments of force are applied to them, each of them will accelerate in different ways. Thirdly, the time needed to achieve maximum strengths in muscles of different muscle groups varies significantly. Fourth, the power capabilities of the muscles depend on such conditions of movement as the speed of movement, internal resistance, the magnitude of the angles in the joints. In addition to all this, the biodynamics of muscle contraction changes significantly if it follows after their stretching. This means that it is impossible in principle to develop one, a rational model of the interaction of the body's biolinks, suitable for all, and based only on fulfilling the requirements of mechanics. Therefore, the search for rational technology mainly goes through the analysis of practical options for performing throw and shock movements by athletes of different readiness and sportsmanship.

The available numerous experimental data confirm that in order to provide the greatest momentum and momentum possible to the body's biolinks and as a result of the greatest final speed of the working link and equipment, the most effective model for the interaction of body links is the sequential "activation" (activation) of them from the proximal to the distal [3; 6; 7; 14; 17; 25]. This model of link interaction does not depend on the type of cast, the age or sex of the performer and the level of preparedness.

The results of our own studies of the dynamics of the speed of the main body biolinks during the shot putt forward by the stereo survey confirmed the rationality of the consistent nature of not only acceleration but also braking of the body links from the bottom up (Fig. 3).

As the qualification of the athlete's increases, the values of the maximum speed of individual parts of the body, starting from the right hip joint and ending with the brush of the throwing arm. In this case, not only the values of the speeds of individual links are important, but also the time of their achievement. Too early the achievement of maximum speed, as well as later, by one link in relation to the other or to the moment of launching the equipment reduces the result. There is an optimal sequence and a tempo-rhythm structure of the movement

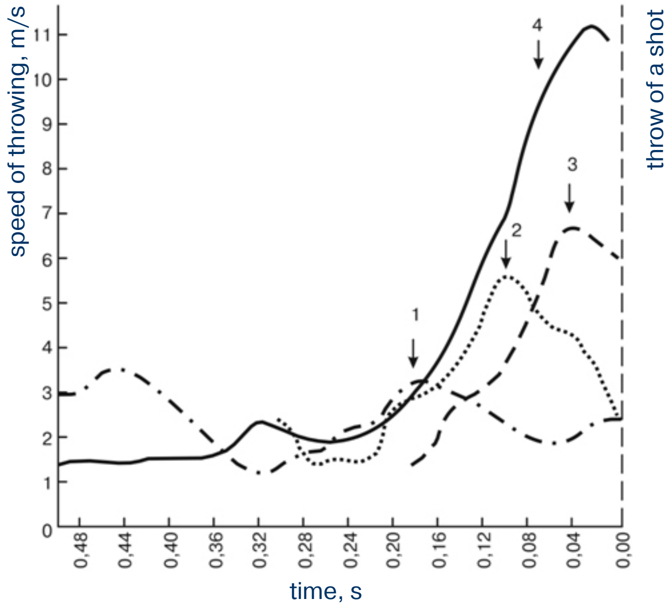

Fig. 3. Speed of the main body bio-links in the phase of the final acceleration of the shot [25]:
1 – right knee joint; 2 – right hip joint; 3 – right shoulder joint; 4 – wrist joint of the right hand. Arrows indicate the maximum speeds.

of the body links, especially massive and strong, at which the highest result is achieved.

The main conclusion that follows from the obtained data is that qualified athletes have a greater similarity in the temporal sequence of movement of the right knee, hip and shoulder joints. In athletes of less-skilled, the spread of these indicators is much larger.

A similar scheme of organization of movements is observed even in the execution of impact (Fig. 4).

Movement begins with the active interaction of the legs with the support, then follows the gradual inclusion of the muscles of the trunk, shoulder girdle and upper limbs, the action is completed by the hand in sequence – the shoulder, forearm and arm with the racket. Consistently from the link to the link, their speeds also increase. Movement of individual parts of the body are subject to one common purpose – providing the necessary amount of mechanical movement to the body of the athlete and the working link in the vertical and horizontal direction [10]. The principle of successive work of body biolinks during a strike in tennis implies the implementation of three strategies [23]:

1) inclusion of body's biolinks at the right time;

2) activation of biolinks from proximal to distal;

3) sequential acceleration and sequential braking of the body's biolinks.

Any shock action can be characterized as a series of time-coordinated translational-rotational movements of body parts. In this case, the proximal units produce more than 50% of the total speed of the end link of the kinematic chain or equipment [18].

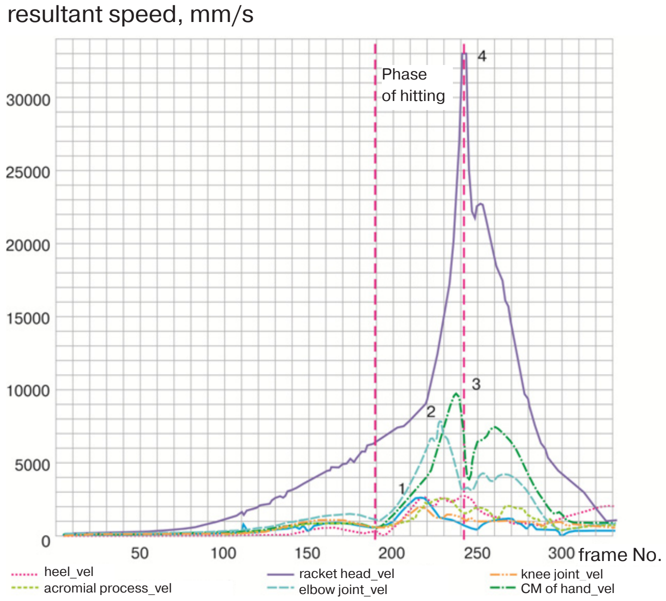

Fig. 4. Speed charts of the center of the joints and racket in the performance of the forehand in tennis [4]:

1 – maximum speed of the right hip joint; 2 – maximum speed of the right shoulder joint; 3 –maximum speed of the CM of the right hand; 4 – maximum speed of the racket head.

What are the mechanisms that ensure the maximum speed of the equipment can underlie the considered principle of interaction of the body links?

It is known that if external forces do not act on the body or system of bodies, then the velocity of the center of mass of the system remains constant (internal forces can not change its motion). However, within the system itself a redistribution of momentum is possible, that is, if the speed of any of the bodies entering the system is reduced (due to the action of internal forces), braking it, it will lead to an increase in the speed of the rest of the system. Of course, the law of conservation of momentum in application to the movements of the athlete does not manifest itself in pure form, because the athlete is affected by external and internal forces (reaction forces of support, friction, etc.), however, it can explain the successive nature of the speed increase body links from the supporting to the workers in shock and throwing movements.

The process of communicating the velocity of the projectile can be divided into two stages. At the first stage, the speed is communicated to the entire system of the athlete-equipment, as a result of which the system acquires a certain amount of movement. At the second stage, due to the braking action of the left foot, and then the right one, the braking of the body links from the bottom upwards. This leads to a decrease in the moving mass of the athlete's body and, as a consequence, to an increase in the speed of the overlying links up to the brush and projectile. In other words, there is a redistribution amount of movements (momentum) between the body links. The speed of movement of links that are successively drawn into the braking wave varies inversely with their mass, that is, the lighter the link, the greater its speed. Thus, the hand with the equipment, being not only the final, but also the lightest links of the system, get the highest speed in comparison with the other links that preceded them in the chain of actions [1].

The second mechanism, ensuring the growth of the speed of the equipment with the subsequent dispersal of the links of the body, is based on the use of the energy of elastic deformation of muscles. In throws and blows, pre-tensioning of muscles is created by overtaking links. When the body link is subsequently activated actively, the proximal joint of the link is accelerated in the direction of throwing. Acceleration of the joint is caused by a so-called articular force, the line of action of which passes through the joint axis [27]. Since the link has a definite mass, that is, it has inertial properties, its distal end lags behind in its motion, turns in the opposite direction to acceleration. As a result, stretching of the muscles takes place, which will participate in the acceleration of the link. As a result, they accumulate the potential energy of elastic deformation, which, with the subsequent contraction of muscles, partially transforms into kinetic energy of the moving link, increasing the speed of its movement.

Such a performance of the rotational movement in sports practice is often called a whip technique. The execution of the movement by the whip technique is based on the fact that the proximal joint first moves rapidly in the direction of throwing or striking, and then is sharply inhibited. This causes a rapid rotational movement of the distal part of the body link. Unfortunately, at present there is no exact data, what is the quantitative contribution, obtained by using the energy of elastic deformation of muscles, into the speed of the working link and the equipment. Indirectly, this can be judged from the contribution of the hand to the rate of emission of the nucleus (about 2 $m \cdot s^{-1}$) and javelin (about 8 $m \cdot s^{-1}$). The movement of the hand at the end of the ejection phase is due to the activity of flexor muscles of the hand and fingers, as well as the forces of elastic deformation arising as a result of the stretching of these muscles by the force acting on the part of the accelerated equipment. The magnitude of the forces of elastic deformation of muscles with the correct performance of the exercise is much greater than the magnitude of the force caused by the activity of muscles [19; 22; 24; 28].

Thus, skillful use of energy of elastic deformation of muscles is one of the main sources of increasing the speed of the working link and equipment [10].

When the muscles are stretched, this occurs when the body links are connected in series, the receptors located in it (neuromuscular spindles), which can lead to a reflex increase in the nervous impulse that comes to the muscle (the so-called stretch reflex).

The mechanism of active control of wave motion in the kinematic chain assumes not only correctly coordinated acceleration of links, which are included in the work, but also their equally strong braking, which is necessary for transferring the impulse along the chain [1]. The need for a clear temporary organization of accelerations and braking of the body links is emphasized by other specialists [1; 8; 9]. Some specialists, emphasizing the importance of the effectiveness of sequential braking of the speed of links in the final phase of throwing or strikes, discussed principle of organization of the interaction of the links of the body is called "principle of transmission (transfer of the kinetic moment in the multi-link kinematic chain" [15] or "principle of the transmission of momentum" [20].

Conclusions

Consecutive dispersal of the body links is an important condition for the rational execution of impact or throws motion. The second equally important condition is the consecutive braking of the body links in the final phase of the movement, which also affects the dispersal of the working link and equipment. These actions transfer the linear and rotational momentum from segment to segment, from the lower part of the body to the top and from the top to the shell, giving him the maximum speed.

When the muscles are stretched, which occurs when the body links are sequentially inserted, the receptors located in it, which can lead to a reflex increase in the nervous impulse that comes to the muscle, and the possibility of using the energy of elastic deformation of muscles, which is one of the main sources of increasing the working speed link and equipment.

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