Journal of Siberian Federal University. Humanities & Social Sciences
2024 17(2): 268–277

EDN: STNNCU
УДК 796.015.12:796.431.4

The Mistakes Causes in the Pole Vaults Entry Phase and Correction Methods

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Received 19.04.2023, received in revised form 17.11.2023, accepted 06.12.2023

Abstract. The evaluation of the rationality of trajectories and positions of body links in various nodal elements of a competitive exercise is an important factor in the qualified athletes training. The modern identification of hidden mistakes and their correction help to prevent their development into an erroneous motor skill. This circumstance determines not only the exact adherence to the movement training algorithm, but also the use of modern biomechanical methods for determining the structure of movement, the ranges of angular changes in the articular joints and the angular velocities between the links of the athlete's body. The article presents the results of a study on identifying typical mistakes that occur in the structural components of the pole vaults entry phase. Based on the identification of the mistakes causes, the effective means of their correction were selected.

Keywords: pole vault, entry phase, movement biomechanics, movement correction, mistakes.

Research area: physical education.

Citation: Bondarenko K.K., Bondarenko A.E., Stepankova A.A., Sevdalev S.V. The Mistakes Causes in the Pole Vaults Entry Phase and Correction Methods. In: *J. Sib. Fed. Univ. Humanit. soc. sci.*, 2024, 17(2), 268–277. EDN: STNNCU

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Причины возникновения ошибок в фазе входа в прыжках с шестом и методы их коррекции

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Аннотация. Оценка рациональности траекторий и положений звеньев тела в различных узловых элементах соревновательного упражнения является важным фактором в подготовке квалифицированных спортсменов. Своевременное определение скрытых ошибок и их коррекция способствуют недопущению перерастания в ошибочный двигательный навык. Данное обстоятельство обусловливает не только точное следование алгоритму обучения движению, но и использованию современных биомеханических методов определения структурности движения, диапазонов угловых изменений в суставных сочленениях и угловых скоростей между звеньями тела спортсмена. В работе приводятся результаты исследования по выявлению типичных ошибок, возникающих в структурных компонентах фазы входа в прыжках с шестом. На основании выявления причин возникновения ошибок подобраны эффективные средства их коррекции.

Ключевые слова: прыжки с шестом, фаза входа, биомеханика движений, коррекция движения, ошибки.

Научная специальность: 13.00.04 – теория и методика физического воспитания.

Цитирование: Бондаренко К. К., Бондаренко А. Е., Степанькова А. А., Севдалев С. В. Причины возникновения ошибок в фазе входа в прыжках с шестом и методы их коррекции. *Журн. Сиб. федер. ун-та. Гуманитарные науки*, 2024, 17(2), 268–277. EDN: STNNCU

Introduction

Pole vaulting is a complex coordinating competitive exercise that includes a mechanism for converting the kinetic energy of the run into the potential energy of vertical movement (Schade et al., 2000, 2006). The mistakes made at the initial stage of the transition from free movement to the actions of the athlete regarding the support on the pole can jeopardize the correct execution of the subsequent phases of the movement (Ogandzhanov et al., 2022). The relationship of kinematic and dynamic parameters of movement is a factor that determines the effectiveness of the competitive exercise. A change in effort in any phase of movement can lead to a change in the trajectory of movement in the joint, which is fraught with injury (Rebella et al., 2008; Grigorenko et al., 2011; Bondarenko et al., 2022).

The effectiveness of the athlete's interaction with the pole is determined by the energy potential of the skeletal muscles (Shilko et al., 2020). The appearance of a number of mistakes in the performance of a technical action is due to the insufficient development of physical qualities that determine the athlete's motor capabilities, or the low functional state of the skeletal muscles that provide the overall structure of the movement (Barris et al., 2014; Bondarenko et al., 2018). The accumulation of energy in skeletal muscles and the amount of its dissipation during the execution of a movement largely depends on the model parameters of movement and the morphological and functional indicators of athletes (Shilko et al., 2016; Ogandzhanov, Mullina 2021).

The formation of optimal trajectories of body links during pole vaults is largely determined by the individual capabilities of the athlete (Cherkasov et al., 2022). To determine the mechanisms of formation of the technical execution of a movement with individual characteristics of the development of the athlete's body, it is necessary to develop complex criteria for assessing the level of general and special preparedness with the level of technical preparedness (Chun-Wum-chul, 2008; Kosikhin, 2009). The assistance in mastering technically correct motor actions in various phases of movement can be provided by the use of special training devices and the use of imitation and lead-up exercises (Voron, 2013).

Taking into account the analysis of literary sources and practical experience in teaching and improving motor actions, we have put forward a hypothesis that in the learning process, the occurrence of mistakes is largely due to the underestimation of the biomechanical parameters of motor action.

The purpose of our study is to identify typical mistakes and select correction means in sports competitive movement.

Materials and methods

Organization of the study

An 18 years old qualified athlete (the candidate for the master of sports in pole vault) with a body weight of 54 kg took part in the study. At the first stage, the analysis of performed jumps in different periods of training and competitive activity was carried out. Through video analysis of movements, mistakes that occurred in the entry phase were determined. The causes of mistakes and the means of their elimination were determined by the method of biomechanical analysis of movements.

Video recording of movement was carried out at a speed of 60 fps. Every fifth frame of the video recording was used for motion analysis.

Method of index description of athlete's movements

To analyze the change in angular displacements, a matrix of index description of the angular velocities of motion based on a 21-link human biokinematic system (according to V. T. Nazarov, 1984) was used. The numbering of biokinematic chains and joints of the human body in the index description of the posture was determined by the following sequence:

Chains: 1 – right leg, 2 – left leg, 3 – right arm, 4 – left arm, 5 – spinal column with head. *Leg joints*: 1 – hip joint, 2 – knee joint, 3 – ankle joint, 4 – metatarsophalangeal joint. *Hand joints*: 1 – shoulder joint, 2 – elbow joint, 3 – wrist joint, 4 – metacarpophalangeal joint. *Spine joints*: 1 – sacro-lumbar, 2 – lumbar-thoracic, 3 – thoraco-cervical, 4 – atlanto-occipital joint (Fig. 1).

To record the changing posture, a simple linear regression equation of the type $Y = a + bX$ was used:

$$\varphi^{t0\to t\kappa}_{abc} = \varphi_{abc} + \omega^{t0\to t\kappa}_{abc} \cdot t$$

where $\varphi^{t0\to t\kappa}_{abc}$ is the articular angle at any moment of time from the beginning to the end of the movement, φ_{abc} is the angle at the moment of observation start, $\omega^{t0\to t\kappa}_{abc}$ is the average angular velocity of this movement from the initial to the final time, t is the time for which articular angle is determined.

$$\omega^{t0\to t\kappa} = \begin{matrix} \omega_{11} & \omega_{12} & \omega_{13} & \omega_{14} \\ \omega_{21} & \omega_{22} & \omega_{23} & \omega_{24} \\ \omega_{31} & \omega_{32} & \omega_{33} & \omega_{34} \\ \omega_{41} & \omega_{42} & \omega_{43} & \omega_{44} \\ \omega_{51} & \omega_{52} & \omega_{53} & \omega_{54} \end{matrix}$$

Fig. 1. Scheme of the matrix recording of the angular velocities of movement in the articular joints of the athlete's body. *Rows – kinematic chains, columns – joints of chains*

Results

The entry phase is the shortest jump phase. At the same time, by performing this phase, one can determine the quality and success of the entire jump. The athlete must place the pole in the box, trying not to lose the kinetic energy accumulated during the run, and at the same time change the direction of movement from horizontal to vertical. To do this, it is necessary to hold the common center of mass high and use the elastic force returned by the pole, converting it into potential energy. Most injuries of athletes occur as a result of intense accumulation of stresses that occur when the kinetic energy of the run is converted into potential energy with the resistance of a bending pole and a change in the position of body segments. The chronophotogram of Fig. 2 shows the key elements of the entry phase, that is, putting the pole into the box, repulsion and bending of the pole. At the moment of repulsion from the support, the upper arm should be in the same projection with the supporting leg. This provides optimal muscle traction for vertical movement. As for the upper limbs, both elbows should be as straight as possible to be able to push and bend the pole.

The position of the athlete's torso at the time of the entry phase must be vertical. Leaning back during this phase can affect the takeoff speed. In addition, this affects the angle approaching the maximum allowable between the pole and the treadmill, as well as the height of the common center of mass at the time of takeoff.

The maximum angle between the pole and the treadmill when placing the pole in the box reduces the angle at which the pole must turn about its axis when moving to a vertical position. This contributes to the efficiency of transferring the energy of movement to the pole. Depending on the height of the grip (as it increases), this angle decreases. This angle is influenced by the height of the jumper and the span of his arms.

Putting the pole in the box marks the beginning of the transfer of energy from the vaulter to the pole. Pre-tensioning the muscles of the torso, shoulders, and arms minimizes this loss of energy. The correct position of the links in the shoulder joint leads to a greater contraction of the extensors of the shoulder due to the reflex reaction of these muscles.

The position of the upper arm should be as high as possible above the head. In this case, the arm should be as straightened as possible. This helps to increase the angle between the pole and the horizontal line at the time of the pole's setting. With weakness of the muscles of the shoulder girdle and arms, there is a decrease in the vertical straightening of the supporting arm.

Fig. 2. Nodal elements in the entry phase when performing a pole vault

At the moment when the cork part of the pole hits the back of the box, the top hand should be directly above the toes of the jogging foot. This contributes to the efficient transfer of energy from the vaulter to the pole. Also, at the moment of take-off, the top arm will be in front of the take-off leg, as the top arm moves forward as the pole flex begins. One of the mistakes at the time of setting the pole is the position of the pushing leg in front of the upper arm. The most biomechanically correct position of the skating leg is directly under the upper arm.

The height of the jump largely depends on the speed of repulsion. The resulting repulsion velocity depends on the magnitude of the horizontal and vertical velocities. The take-off angle should be in the range of 18–20 degrees.

The bending of the pole occurs with the help of the lower hand. This begins when the pole is placed in the box and continues for a short period until the legs leave the track. The pushing action of the lower hand plays an important role in initiating the bending of the pole. However, it slows down the rotation of the jumper.

The force generated by the downward action of the arms towards the pivot point of the pole is the force that is responsible for bending the pole. The greater this force, and the further the point of application of this force from the anchor point of the pole, the easier it is to bend it. This is facilitated by the maximum removal of the pole with the upper hand. In this case, the mistake is the traction with this arm or its flexion in the elbow joint. The vertical position of the body contributes to an increase in the force that bends the pole. The pulling force of the lower arm at the beginning of the pole flexion helps the vaulter to perform an upside-down body flip.

The movement of a person is carried out due to changes in the articular angles, which perform a control function in relation to the integral movement. By indexing the posture and determining changes from the previous moment, it is possible to accurately quantify the movement process and analyze it. We determined the average values of the angular velocities in the female athlete's articular joints between the nodal elements of the entry phase in six attempts (Fig. 3)

When evaluating the effectiveness of a motor action, the interaction of the athlete's body with other bodies is taken into consideration. At the same time, the athlete's body changes its mechanical characteristics of movement. At the same time, control and natural forces acting on the body are distinguished. Control forces arise as a result of joint movements, while natural forces act on the body in the absence of changes in posture.

Information about the parameters of the action of forces on the body gives an idea of the nature of changes in its positions. This makes it possible to evaluate the effectiveness of the performed motor actions.

Based on the dynamic parameters of the movement, the control forces were determined when performing a pole vault (horizontal acceleration, vertical acceleration, moment of force) and natural forces (horizontal force component, horizontal component of the support reaction force, vertical component of force, gravity, vertical component of the support reaction force, the sum of the squares of the horizontal and vertical components of the support reaction forces, resultant support reaction force, shoulder of force) affecting the performance of the technical element (Table 1).

$$\boldsymbol{\omega}^{0,03} = \begin{matrix} 0{,}55 & 23{,}92 & 8{,}90 & 0 \\ 5{,}68 & 4{,}96 & 16{,}23 & 0 \\ 0{,}55 & 37{,}69 & 37{,}69 & 0 \\ 15{,}77 & 0{,}63 & 37{,}69 & 0 \\ 2{,}14 & 0 & 0 & 14{,}56 \end{matrix}$$

a

$$\boldsymbol{\omega}^{0,04} = \begin{matrix} 22{,}28 & 26{,}56 & 9{,}43 & 0 \\ 1{,}89 & 3{,}69 & 7{,}02 & 0 \\ 3{,}64 & 2{,}19 & 37{,}69 & 0 \\ 9{,}80 & 1{,}11 & 37{,}69 & 0 \\ 2{,}24 & 0 & 0 & 11{,}83 \end{matrix}$$

b

Fig. 3. Change of angular velocities (rad/s) in the articular joints between the nodal elements of the entry phase: a) putting the pole into the box and repulsion; b) between repulsion and bending the pole

Table 1. Forces and moments of force of support reactions to various nodal elements in the entry phase

	Putting a pole in a box	Repulsion	Pole bending
Horizontal acceleration, $a_{x,}$ м/с^2	-8,40	-80,85	-14,44
Horizontal force component, F_x, Н	-453,6	-4365,9	-779,625
Horizontal component of the support reaction force, R_x, Н	-453,6	-4365,9	-779,625
Vertical acceleration, a_y, м/с^2	4,2	3,15	6,9125
Vertical component of force, F_x, Н	226,8	170,1	373,275
Gravity, G, Н	529,74	529,74	529,74
Vertical component of the support reaction force, R_y, Н	756,54	699,84	903,015
The sum of the squares of the horizontal and vertical components of the support reaction forces, $R_x^2 + R_y^2$	778105,7316	19550858,84	1423251,231
Resultant support reaction force, $R_{res.}$ (Н)	882,10	4421,64	1193,00
Shoulder of force, $d_{(м)}$	0,8600245	2,2854219	-3,2885832
Moment of force, M, (Н*м)	758,63	10105,30	-3923,28

Depending on the nodal element of the movement, the athlete changes the value of her moment of inertia, bringing the links of the body closer to the axis of rotation or moving them away from it. This happens both depending on the structure of the technical element, and on the forces created at each particular moment. The action of control and natural forces, as well as the efforts created by the force of muscle traction in the joints, allow movement along optimal trajectories. At the same time, a deviation from the optimal kinetic parameters can lead to deviations in the kinematics of motion, which determines the occurrence of mistakes.

Estimation of kinematic parameters of execution of the entry phase

Performing a movement with a deviation from the model parameters of a technical action that affects its result is a mistake. The same category should also include those movements that, as a result of the action of forces, are ineffective. An analysis of the occurrence of mistakes can make it possible to timely correct the individual use of the means and methods of preparing a jumper.

Video analysis of the performance of the pole vault in the entry phase revealed the presence of two mistakes in the performance of the action. The first mistake was to bend the front arm at the elbow joint. The second mistake was in the deviation of the body from the vertical at the moment of bending the pole (Fig. 4).

Considering the causes of these erroneous positions, it is possible to single out the most common ones, namely: insufficient level of development of certain physical qualities, pain sensations or fatigue of the agonist muscles, misunderstanding of the motor task, inconsistency with the individual characteristics of the athlete in the rigidity of the pole, negative transfer of motor skills. In our opinion, the possible cause of the first mistake is the insufficient strength of the extensor muscles of the forearm, as well as the consequence of an incorrect position of the torso. The cause of the second mistake can be attributed to weak muscles of the back, shoulder girdle and abdominal muscles, as well as the spade of the pushing leg at the moment of repulsion.

The means of mistakes correction of the entry phase

Correction of mistakes, depending on the causes of their occurrence, is possible either by using corrective and imitation exercises, or by increasing the performance of the skeletal muscles responsible for providing movement in a particular segment of the body. In particular, to correct the position of the body in the nod-

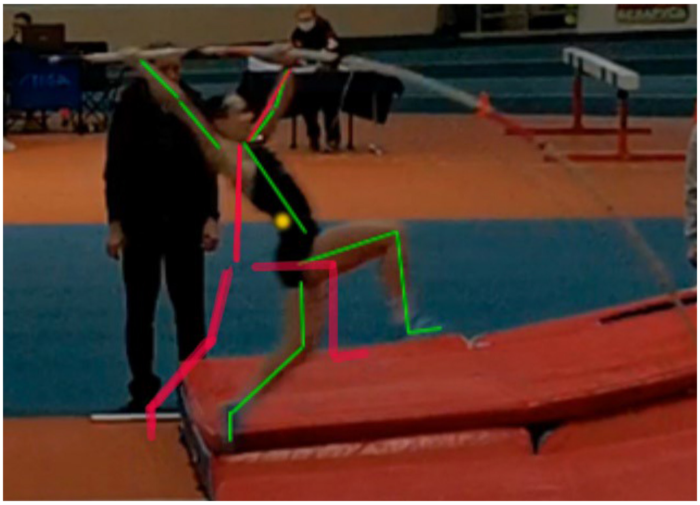

Fig. 4. The manifestation of mistakes during the bending of the pole
(red color indicates the model parameters of the correct position of the body links)

Fig. 5. Simulation exercises for movement correction and mistakes correction

al position of the pole flexion, an exercise was proposed to hold the back with an imitation of the entry phase (Fig. 5). At the same time, the emphasis was put on keeping a straight back with full extension of the front arm at the moment when the pushing leg performed an imitation of repulsion without breaking away from the support.

Another corrective exercise is to perform a take-off repulsion from the support base with an emphasis on maintaining the vertical position of the torso and the straight front arm while bending the pole (Fig. 6).

To correct the mistake in the deviation of the athlete's body from the vertical at the moment of repulsion, an imitation exercise was used with the transition from horizontal run-up to vertical movement without reaching the place of repulsion. The exercise was performed with 2–4 running steps (Fig. 7). After the formation of the skill, the run-up was corrected.

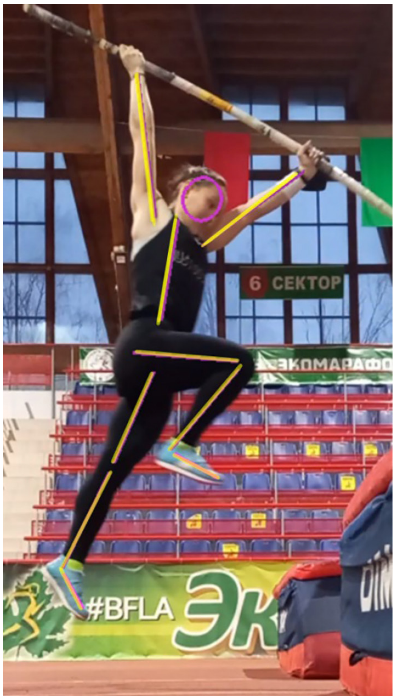

Fig. 6. Imitation exercise for correcting the position of the body links with take-off repulsion from the support base

Fig. 7. Performing a simulation exercise with a change in the take-off point in the run

Discussion

The principle of structured construction of movement systems, implemented in the formation of a motor skill, determines the integrity and perfection of actions. Changing one of the components of the movement can lead to reduced performance or risk of injury.

Evaluation of the rationality of trajectories and positions of body links in various nodal elements of a competitive exercise is an important factor in the preparation of qualified athletes. Timely identification of hidden mistakes and their correction help to prevent the development into an erroneous motor skill. This circumstance determines not only the exact adherence to the movement training algorithm, but also the use of modern biomechanical methods for determining the structure of movement, the ranges of angular changes in the articular joints and the angular velocities between the links of the athlete's body.

The causes of structural mistakes do not always lie on the surface. In this regard, the most effective way of their occurrence is the construction of model characteristics of the movement, on the basis of which the resulting deviations are fixed.

Conclusions

The structural components of the pole vault performance are determined by the kinematic and dynamic parameters of the movement. The kinematic parameters of the performance of a competitive exercise should include angular displacements in the articular joints and their angular velocities, which ensures the movement of the athlete's body along the optimal trajectories. Pole vault dynamic parameters include control forces (horizontal acceleration, vertical acceleration, moment of force) and natural forces (horizontal force component, horizontal component of the support reaction force, vertical component of force, gravity, vertical component of the support reaction force, the sum of the squares of the horizontal and vertical components of the support reaction forces, resultant support reaction force, shoulder of force).

Based on the study, typical mistakes that occur in the structural components of the entry phase in pole vaults were identified. Based on the identification of the causes of mistakes, the effective means of their correction were selected.

The results of the study can be used by coaches to improve the structure of pole vault training. The use of imitation and modeling exercises in the training process contributes to the formation of the optimal technique of motor action.

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