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BIOMECHANICAL AND KINETIC ASPECTS OF ACROBATIC ELEMENTS IN POLE SPORT

In the modern sports environment, pole sport is becoming increasingly popular. It combines elements of gymnastics, acrobatics, and dance techniques. Despite the growing interest in this sport, scientific research on its biomechanical aspects remains insufficiently studied. The peculiarities of performing acrobatic elements, the distribution of the load on the musculoskeletal system, and the risks of injury require a detailed analysis.

The purpose of the article. *This research aims to analyze the biomechanical features of acrobatic elements in pole sport, define key factors influencing exercises' technical performance, and estimate risks of injuries. The article discusses the main kinematic and kinetic parameters of movements and the influence of physical training on the efficiency of performing elements.*

Methodology. *The research is based on a comprehensive analysis of literature, empirical data on athletes' movement patterns, and biomechanical characteristics of key element performance. Video analysis and three-dimensional kinematic evaluation were used, which allowed objective information about the distribution of load during the exercise.*

Scientific novelty. *The work expands the scientific understanding of the influence of muscle activity and strength characteristics on the efficiency of performing elements in pole sport. For the first time, a detailed analysis of muscle symmetry and asymmetry in athletes was carried out, which allows the development of personalized training programs to correct imbalances.*

Conclusions. *The study's results confirm the importance of an individual approach to the physical training athletes engaged in pole sport. Optimization of power balance and proper load distribution allows for improvement in performance techniques and reduces the risk of injury. Further research in this area can be aimed at improving training methods, using digital technologies for movement analysis, and integrating psychophysiological approaches to athletes' training.*

Keywords: *pole sport, biomechanics, kinematic analysis, muscle balance, injuries, physical training.*

Statement of the problem. At the present stage of the development of pole sport, high results at international competitions are impossible without an effective system of training athletes. Technical training is essential to the training process, which determines the elements' efficiency, stability, and variability. The latest advances in biomechanics and innovative technologies allow for objective control of movements, analysis of the load on muscles and the osteoarticular system, and correction of errors. High achievements in this discipline depend on physical and psychological fitness levels and the technical skill of performing the elements. One of the key problems in the training process is the difficulty of objectively analyzing an athlete's movements without using modern innovative technologies. Biomechanical methods allow us to assess movements' kinematic and kinetic parameters, determine the degree of asymmetry and the efficiency of force distribution, and identify areas for improving technique.

Biomechanics technologies are evolving yearly, offering new tools for analyzing movements in sports disciplines, including pole sports. The use of video analysis, platforms for assessing reactive load on limbs, and programs for 3D visualization of movements expand the possibilities of the training process, allowing for an in-depth analysis of athletes' technical fitness [2]. An important task of modern sports science is to systematize the existing biomechanical analysis methods and find new technological solutions to ensure effective control of the athlete's motor activity at different stages of long-term training.

Analysis of scientific sources. Pole sports have undergone significant development and popularization in recent decades, especially among amateurs. Thanks to the efforts of international organizations such as the International Pole Sports Federation (IPSF), this sport has become a professional discipline with clear evaluation rules, developed training programs, and international championships. Pole sports combine elements of acrobatic gymnastics and dance on a vertical apparatus, and its roots can be traced back to Western traditions and Eastern martial arts, mainly Chinese and Indian «Mallakhamb» [1; 3; 5].

Despite the rapid growth in the popularity of pole sports, the number of scientific studies in this area remains limited [2]. Recent epidemiological studies confirm that the shoulder girdle and wrist joints are the most stressed in pole sports, making them the most vulnerable to injury. The most common injuries are sprains, bruises, and friction problems during contact with the projectile [3; 6; 9]. Data analysis shows that professional athletes suffer more injuries than amateurs and have an increased tendency to re-injury.

The risk of injury depends on age, height, training frequency, and total duration of training, with an increase in hours devoted to pole training correlating with an increased incidence of injury [7; 8]. Some key elements, such as handspring, splits, and rotational movements (carousel), have the highest risk of injury [5]. In general, non-contact injuries account for 57.3% of all cases, with repetitive rotational movements of the shoulder and front splits being the most problematic [3].

Particular attention should be paid to the impact of muscle imbalance on the risk of injury in pole vaulting. I. Zharova and G. Antonova note that in athletes who regularly perform dynamic transitions and splits, the pubic bone changes due to overload and imbalance of the pelvic muscles [11]. In particular, the long adductor muscle of the thigh creates an opposition to the transverse abdominal muscles, which can cause tears of the tendon fibers at their attachment to the pubic bone (2010). The research of Tsyhykalo et al. (2011) confirms that excessive load on the abdominal muscles and hips can lead to disorders of power balance, manifested in decreased stability when performing complex figures on the pole [1; 9].

Also relevant are the studies of Morales-Conde (2010), who indicate that increased intra-abdominal pressure when performing splits and inversions can cause stretching of the transverse fascia and weakening of the inguinal canal, which potentially increases the risk of developing a sports hernia. In pole sports, this phenomenon can be caused by constant loads on the pelvic muscles during the body's fixation on the pole [7].

Data from Ioffe & Negria (2020) confirm that in athletes who experience high loads in the groin area, an MRI examination shows an increase in signal from the structures of the inguinal canal and the upper branch of the pubic bone, indicating chronic overload. If high loads are maintained without proper technique correction, this can lead to degenerative changes in tissues and an increased risk of injury [4].

A general analysis of scientific sources demonstrates that although pole sport has unique biomechanical characteristics, its traumatic aspects are often similar to those observed in gymnastics and acrobatics.

Based on the analysis of modern scientific data, the purpose is to reveal the tendencies of the development of biomechanical assessment of the technical fitness of athletes in pole sport and to define the most effective technological approaches to the analysis of motor actions. The methods of theoretical analysis, systematization, and generalization of modern scientific and methodological literature, as well as the study of current research in the field of biomechanics of movements, were used in the work.

Methods of the research. The biomechanical aspects of pole sports research are based on an integrated approach that combines the analysis of scientific sources, systematization of existing knowledge, and generalizing modern methodological approaches to study the mechanics of movements in sports disciplines.

This study was conducted using theoretical methods that provide a comprehensive analysis of the problem and allow us to assess the topic's level of scientific development.

1. *Theoretical analysis* – a study of modern scientific sources related to the biomechanics of pole sport, traumatology, kinematic and kinetic aspects of movements, and technologies used for their evaluation. Studies on acrobatics, artistic gymnastics, and related disciplines with similar load characteristics on the musculoskeletal system were considered.

2. *Systematization and generalization* – a structured analysis of scientific and methodological literature was carried out, which made it possible to identify the main trends in the field of research of biomechanics of pole sport. The generalization of the obtained data allowed us to formulate the main problems that need further study, particularly the influence of asymmetry of loads, kinematic features of the key elements, mechanisms of occurrence of injuries, and ways of their prevention.

3. *Analysis of Internet resources* – Scientific databases such as PubMed, ScienceDirect, Google Scholar, MDPI, and ResearchGate, containing modern research in the fields of biomechanics, sports science, and rehabilitation, were used. Particular attention is paid to the works covering electromyography (EMG), kinematic sensors, 3D modeling, and other methods to assess the athletes' body's loads during the performance of elements on the pole.

The literature analysis took into account relevant scientific works that consider such aspects as:

– Kinematic and kinetic characteristics of movements in pole vaulting (Ignatoglou et al., 2024).

– Asymmetry of muscle loads and its impact on the musculoskeletal system (Antonova, 2023).

– Muscular imbalance and injuries in athletes performing splits and inversions (Garvey, 2010; Tsyhykalo et al., 2011).

– Development of traumatic changes in the inguinal region due to intense training (Morales-Conde, 2010; Ioffe & Negria, 2020).

Adequate body support in the air and, in the context of pole sport, its stabilization and retention on the pole are due to the interaction of several kinesiological factors. One key aspect is the coordinated activity of muscle groups that ensure a change in body position and the performance of motor tasks.

Firstly, any movement in space results from the integrated activity of several muscle units, and the dominant role does not always belong to the primary muscle or direct kinematic interaction with bone structures. For example, when the hip is flexed over 90°, there is a variation in the activation of the flexor muscles. They make

the main contribution to this movement. iliacus and m. psoas major, as other flexors (in particular, the m. rectus femoris and m. sartorius) demonstrate limited efficiency in this flexion range.

In addition, given the anatomical and functional features of some hip flexors that cross both the hip and knee joints, the kinematic efficiency of the movement depends mainly on the relative position of these joints – for example, the level of activity of the m. Rectal femoris will vary depending on the degree of flexion or extension in the knee joint.

Muscle asymmetry should be noted separately. It can significantly affect the limb load distribution and determine the individual biomechanics of movements. In particular, asymmetry in the tone or strength of the hip flexors can cause a shift in the force load vector, which in turn affects the stability of the hip joint and the overall efficiency of movement.

It is worth noting that similar biomechanical principles apply to other joint movements. The above example illustrates how body position, amplitude of movements, and complex muscle interaction affect a movement's kinematic and kinetic characteristics [5].

Secondly, athletes' movements in pole vaulting rarely correspond to the classical schemes of kinesiological «correct» patterns, and the position of the body and limbs directly affects the action of gravity, load distribution, and the nature of muscle activity. For example, when performing the human flag element, gravity causes the upper leg to be brought into the hip joint and the lower leg to be pulled away. This leads to differential muscle activation: in the upper leg, the hip abductor muscles are more active to counteract gravity, while in the lower leg, the main load falls on the hip adductor muscles, which stabilize the limb in a neutral position [10].

Additionally, on a dynamic pole (with the possibility of rotation), it is necessary to generate significantly greater muscle forces to control movement and stabilize the body. In this context, muscle involvement varies depending on the direction and speed of rotation, which imposes additional requirements on neuromuscular coordination.

To simplify the analysis (and better understand the basic principles), this discussion focuses mainly on the influence of gravity without taking into account the rotational components that occur during movement on a dynamic pole. The influence of these factors is highly variable and depends on both the vector and speed of rotation and the individual characteristics of the athlete's muscle activity.

Epidemiological studies in pole sports show that the shoulder and wrist joints are the most vulnerable to injuries due to the high level of load during the performance of dynamic elements and static holds on the pole. Injuries associated with contact with the projectile mostly include sprains, bruises, and skin damage due to friction [2; 5-8].

An analysis of the frequency and nature of injuries shows that professional athletes suffer injuries more often than amateurs and have an increased tendency to re-injure themselves [6]. The risk of injury increases under the influence of several factors, including age, height, frequency, and duration of training. The time spent training with specialized pole elements directly correlates with higher injury rates [7; 8].

Certain elements and positions are much more likely to cause injuries. The most traumatic are handsprings, splits, and rotational movements on the pole (carousel), as they involve significant loads on the shoulder girdle, hip joints, and core muscles [7].

In general, non-contact injuries are the most common, with repetitive rotational movements of the shoulder and front twine poses identified as the most common causes of overloads and microtrauma [2]. This confirms the need to optimize movement techniques, implement individualized programs to develop muscle balance and use biomechanical analysis to prevent injuries in athletes.

Fig. 1. Position «Unilateral hold with torso deflection»

Fig. 2. Position «Bilateral hold in upright position»

For a more illustrative example, we analyzed two movements of the athlete on the pole (Fig. 1 and Fig. 2), and the analysis of the exercises is presented in a tabular analysis of muscle loads in different positions on the pole (Tab. 1).

Table 1

Analysis of muscle loads in different positions on the pole

Parameter	Position 1 (unilateral hold with torso deflection)	Position 2 (bilateral hold in an upright position)
Kinematics	– The torso is curved backwards; the center of mass is shifted towards the working arm.	– The torso is vertically pressed against the pole – The center of mass is located along the body axis.
The main points of contact	– Working hand – Minimal foot contact with the pole for stabilization.	– Both arms – The torso fits snugly against the pole for stability.
Major muscles of the upper body	– Working arm: deltoid muscles (deltoideus), trapezius muscles (trapezius), biceps. – Back muscles: latissimus dorsi.	– Both arms: trapezius, deltoid, biceps. – The latissimus dorsi provide traction.
Muscles of the torso	– Transverse abdominal muscle (transversus abdominis). – Oblique abdominal muscles (obliquus externus/internus). – Multifidus muscles of the back (multifidus).	– The oblique abdominal muscles provide for the fixation of the torso. – The rectus abdominis muscle maintains vertical stability.
Lower limb muscles	– The back of the thigh (hamstrings) to keep the legs in a static position. – Calf muscles (gastrocnemius).	– The quadriceps femoris and calf muscles ensure an extended leg position.
Load distribution	– Unilateral load: the main emphasis is on the dominant arm and the side of the body – Asymmetry due to minimal work of the non-dominant arm.	– Uniform load distribution between arms and torso – Minimal asymmetry ія.
Asymmetry	High: the dominant party does most of the work.	Minimal: both parties are equally involved.
Risk of injury	– Overloading of the shoulder joint – Risk of microtraumas in the lower back due to asymmetrical bending.	– Low risk of injury with proper technique. – Possible overstrain of back muscles if held incorrectly.

In pole sports, the effectiveness of performing complex elements directly is moderate. Consider the athlete's ability to control the position of his or her body, actively counteract gravity, and stabilize joints under increased stress. One of the key aspects is the condition of the shoulder joint, which is inherently unstable and largely depends on muscle control [7]. In this context, it is important to consider the biomechanics of the Twisted Grip, one of the most potent grips that requires a high level of shoulder strength and stability.

When performing the Twisted Grip, the shoulder undergoes significant internal rotation, which leads to a reduction in subacromial space. This stresses the rotator cuff tendons and other intra-articular structures, primarily where the arm supports the body weight. In this position, the shoulder's external rotators are elongated and forced to contract actively, which is a severe test for the stabilizer muscles. If these muscles are underdeveloped, there is a risk of overloading passive structures such as the joint capsule, ligaments, and tendons. This, in turn, can lead to impingement syndrome, microinstability, and shoulder pain [7].

It is important to understand that decreased space in the shoulder joint is not pathological because such changes occur every time, we raise our arms above our heads or hang from the horizontal bar. However, the shoulder girdle muscles do not have sufficient strength to stabilize the humerus. In that case, the athlete is actually «hanging» on the ligaments and capsule, significantly increasing the risk of injury. That is why Twisted Grip requires significant training and gradual rotator cuff muscle strength development before being used in complex elements.

Despite the possible risks, this grip is one of the most effective in pole vaulting, as it allows the athlete to use muscle strength to support their weight optimally. Mastering the Twisted Grip with proper technique and sufficient muscle stability significantly increases movement efficiency and reduces the risk of injury. That is why developing strength and shoulder joint control are critical to performing this element safely.[1]

Effective control of the shoulder girdle position is a key factor in preventing injuries and improving the technical execution of elements in pole sports. While internal rotation of the shoulder in the overhead position can put additional pressure on the subacromial structures, external rotation, and proper scapular kinematics help to balance the load and reduce the risk of impingement syndrome [4].

[1] Rotator Cuff Injury – Who Shoulders The Burden | Watermans. https://watermans.co.uk/help-and-advice/rotator-cuff-injury-who-shoulders-the-burden/

Thus, the movements of the shoulder girdle and shoulder joint are interdependent. Their correct coordination provides optimal mechanics for performing complex elements in pole sport. The scapula, a key structure for stabilizing the shoulder joint, is actively involved in all upper limb movements. Its upward rotation, which is necessary for effective arm lifting, is accompanied by the tension of the anterior dentate muscle and trapezius muscle, which create the so-called “power couple” that rotates the scapula upward and outward.

Performing elements in a head-down position, such as a handstand or a one-armed hang, puts more stress on the scapular stabilizers. If these muscles are not sufficiently active or work in an imbalance, compensatory hyperactivity of the latissimus dorsi muscle can occur, causing excessive internal rotation of the shoulder. This, in turn, can reduce subacromial space and increase the likelihood of impingement syndrome [8].

To avoids this, it is important to ensure the correct position of the shoulder girdle. When raising the arm above the head, the athlete should activate the middle and lower fibers of the trapezius muscle to stabilize the scapula and the anterior dentate muscle, which will promote its upward rotation. Allows the load to be evenly distributed between the stabilizing muscles, preventing excessive stress on specific muscle groups and passive structures of the shoulder joint.

An additional factor that affects the stability of the shoulder girdle is the level of activation of the rotator cuff muscles. When holding the body in inversion positions or during strength holds (e.g., in the flag), these muscles should provide dynamic stabilization of the humeral head. If they are not sufficiently developed, this can lead to microinstability of the shoulder joint, which in the long term increases the risk of traumatic overloads [7].

Thus, the adequate performance of shoulder girdle movements in pole sports requires coordinated work of all muscle groups. Proper interaction of the scapula stabilizers, rotator cuff, and shoulder girdle muscles ensures the safe performance of elements and minimizes the risk of injury. Control of shoulder rotation, uniform load on the stabilizing muscles, and maintenance of the scapular rhythm determine the efficiency and safety of movements in the vertical plane.

Since the shoulder girdle movements are inextricably linked to the scapula, an important aspect is the correct shoulder blade rhythm, i.e., a coordinated relationship between the shoulder joint and the scapulothoracic joint. A coordinated upward rotation of the scapula is required to achieve full arm elevation above the head, which is ensured by the activity of the anterior dentate muscle and the upper and lower trapezius muscle bundles. If this mechanism is impaired, there is an increased risk of overloading the rotator cuff and developing functional instability of the shoulder joint [10].

The scapula plays a crucial role in the stability of the shoulder joint[2], as it is the basis for the attachment of the key muscles responsible for controlling arm movement. In pole sports, the stability of the scapula is essential when performing dynamic movements, when it is necessary to support the body in space using the strength of one or both arms. For example, in positions that involve a significant load on the shoulder girdle (handstand, hanging on one arm), proper scapular positioning helps to reduce the load on the rotator cuff muscles by distributing it between the pectoralis major, trapezius, and latissimus dorsi muscles.

Insufficient scapular stability can lead to scapular winging when the medial edge of the scapula moves away from the chest due to weakness of the anterior dentate muscle or impaired coordination of the shoulder girdle muscles. This reduces the efficiency of movement and increases the risk of overloading the joint structures, which is especially critical when performing supports or dynamic changes in body position on the pole.

Conclusions. Analyzing the biomechanics of bending movements in pole sport requires considering muscle interaction, joint position, and asymmetry. If athletes perform elements safely, controlling shoulder movement and activating stabilizers, particularly the trapezius muscle, which stabilizes the scapula, is important. The optimal distribution of the load between the shoulder, scapula, and spine reduces the risk of injury and improves the kinematics of movement. Also important is the role of the pectoralis major muscle, which controls the limb's position and prevents impaired shoulder girdle mechanics.

Further research in the biomechanical analysis of pole sport can be directed to several key areas. First, an in-depth study of the kinematic and kinetic parameters of athletes' movements during the performance of dynamic elements is necessary, particularly the analysis of the phases of rotation, grip with the pole, and transitional phases between movements. Research in this area can help develop optimal performance techniques and reduce the risk of injury. Further research in this area could improve training methods, use digital technologies for movement analysis, and integrate psychophysiological approaches to athletes training.

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БІОМЕХАНІЧНІ ТА КІНЕТИЧНІ АСПЕКТИ ВИКОНАННЯ АКРОБАТИЧНИХ ЕЛЕМЕНТІВ У POLE SPORT

У сучасному спортивному середовищі pole sport набуває все більшої популярності, поєднуючи елементи гімнастики, акробатики та танцювальних технік. Незважаючи на зростаючий інтерес до цього виду спорту, наукові дослідження з його біомеханічних аспектів залишаються недостатньо вивченими. Особливості виконання акробатичних елементів, розподіл навантаження на опорно-руховий апарат і ризики травматизму потребують детального аналізу.

Мета статті. *Метою даного дослідження є аналіз біомеханічних особливостей виконання акробатичних елементів у pole sport, визначення ключових факторів, що впливають на технічне виконання вправ, а також оцінка ризиків травматизму. Стаття розглядає основні кінематичні та кінетичні параметри рухів, а також вплив фізичної підготовки на ефективність виконання елементів.*

Методологія. *Дослідження базується на комплексному аналізі літературних джерел, емпіричних даних про рухові патерни спортсменів, а також біомеханічних характеристик виконання ключових елементів. Було використано методи відеоаналізу та тривимірної кінематичної оцінки, що дозволило отримати об'єктивну інформацію про розподіл навантаження під час виконання вправ.*

Наукова новизна*. Робота розширює наукове розуміння впливу м'язової активності та силових характеристик на ефективність виконання елементів у pole sport. Вперше проведено детальний аналіз м'язової симетрії та асиметрії у спортсменів, що дозволяє розробити персоналізовані тренувальні програми для корекції дисбалансів.*

Висновки. *Результати дослідження підтверджують важливість індивідуального підходу до фізичної підготовки спортсменів, що займаються pole sport. Оптимізація силового балансу та правильне розподілення навантаження дозволяє покращити техніку виконання та зменшити ризик отримання травм. Подальші дослідження у цій сфері можуть бути спрямовані на вдосконалення тренувальних методик, використання цифрових технологій для аналізу рухів та інтеграцію психофізіологічних підходів до підготовки спортсменів.*

Ключові слова*: pole sport, біомеханіка, кінематичний аналіз, м'язовий баланс, травматизм, фізична підготовка.*

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