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Original Article

Static-dynamic stability of gymnasts' bodies on the rings apparatus

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Abstract.
The aim of the study was to investigate the rational mechanisms of static-dynamic stability of the body of gymnasts of different skill levels when performing exercises on the rings apparatus. **Materials and methods.** Seventeen qualified athletes (I sports category) and ten highly qualified athletes (Honored Masters of Sport, International Masters of Sport) participated in a 4-week descriptive experiment. The study examined the characteristics of performing a large backward rotation on the rings apparatus by athletes of different skill levels. Each athlete performed three attempts, with a 5-minute rest period between attempts. The athletes' movements were recorded using the "Contemplas" mobile video recording and analysis system with a resolution of 150 frames per second, followed by quantitative and qualitative biomechanical analysis and statistical data processing. The kinematic indicators of the gymnasts' movement technique were used to study the mechanisms of posture regulation as a component of the body's static-dynamic stability. As an integral indicator of the gymnast's body statodynamic stability during the backward giant swing, the oscillation of the rings in the sagittal plane was recorded in the final phase of the movement. **Results.** The static-dynamic stability of an athlete should be considered as a multifactorial phenomenon that takes into account the specifics of the conditions for the implementation of programmed sports movements, while identifying effective mechanisms for regulating body posture with the subsequent development of methodologies, techniques, individual training programs, etc. The results of the study show that a rational mechanism ofstatic-dynamic stability of a gymnast's body is one in which there is a balance of forces acting on his body on both sides of the conditional vertical when performing a descent and ascent (ensuring the symmetry of the trajectory of the athlete's body center of mass), as a result, there is no horizontal swaying of the rings in the handstand after performing large turns on the rings (oscillations do not exceed 0.05-0.07 m); a prerequisite for this is the movements of open and closed kinetic chains, which are implemented as an integral and coordinated mechanism under the leading role of the connecting links of the body – the pelvis and lumbar spine, which transmit and coordinate mechanical impulses in conditions of constant change in the interaction of the athlete's body kinematic chains and the state of support. **Conclusions**. Thus, in conditions of mobile support, the stability of the athlete's body is largely determined by the stability of the lumbar-pelvic complex, which plays an important role in ensuring the balance of the whole body. At the same time, the lumbosacral complex should be considered as a part of the body that includes the lower torso and pelvis, which actively interact with the upper torso and thighs.
Key words: balance, rational mechanisms, sports gymnastics, rings exercises, technology.

Introduction

Technical preparation remains one of the key components in the overall system of athletic development. For biomechanics, as the science studying the characteristics of movement in living systems, the motor actions demonstrated by athletes in complex coordination sports, particularly gymnastics (Litvinenko et al., 2014; Potop et al., 2015; Aleksić-Veljković et al., 2019), present a significant area of research interest. In this context, specialists dedicate considerable attention to issues concerning movement coordination, body balance, and the maintenance of athlete equilibrium. This subject is broadly represented in scientific literature.

According to Dallas et al., 2024, balance, along with control of the body's center of gravity, is one of the key elements necessary for achieving higher athletic performance and one of the most basic parameters in gymnastics, playing an important role in the successful execution of athletic skills and in preventing injuries. Therefore, the authors conducted a systematic review of sources on the assessment of balance in artistic gymnastics.

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Experts emphasize the importance of developing balance skills in gymnasts at an early stage of athletic training. The study by Akın, 2013, demonstrates the positive effects of gymnastics training on the development of balance in children aged 4-6 years. Opala-Berdzik et al., 2021, note that young gymnasts have better functional stability compared to their peers who do not practice gymnastics. Petran et al., 2024, studied the characteristics of the development of the vestibular apparatus in gymnasts aged 6-10 years. In an experimental study, Yu et al., 2025, demonstrated the positive effect of special gymnastic exercises on the balance ability of children aged 3-6 years. Muehlbauer et al., 2022, investigated the effect of upper limb movements of young gymnasts when performing balance exercises of varying degrees of difficulty.

The scientific community considers proprioception to be an important factor in the static stability of gymnasts' bodies (Mihăilescu et al., 2018; Fallas-Campos et al., 2023) as an important component capable of integrating sensory signals from various mechanoreceptors to determine body position and spatial movements.

Considering the importance of ensuring the balance of gymnasts' bodies, researchers Hedbávný et al., 2013; Kochanowicz et al., 2015 analyzed the handstand as one of the basic motor structures in artistic gymnastics from the perspective of body balance processes; Litvinenko et al., 2015 investigated the characteristics of the static-dynamic stability of gymnasts of different skill levels; Krištofič et al., 2018 focused their research on assessing the impact of an intervention program on the postural stability of gymnasts; Kyselovičová et al., 2023 studied the influence of isokinetic leg muscle strength on postural stability in gymnasts; Abuwarda et al., 2024 investigated the effect of high-intensity interval training on different types of surfaces on body balance, explosive strength, etc.; Ikonomi et al., 2025 focused on measuring the body balance of gymnasts, which, according to the authors, provides valuable information for programming muscle work.

It should be noted that the issue of static-dynamic stability is also actively researched in other sports (Hrysomallis, 2011; Howerton, 2012; Litvinenko et al., 2018; Pryimakov et al., 2021; Achilleopoulos et al., 2022), indicating the high significance of this issue.

However, despite numerous scientific studies, the problem of static-dynamic stability and maintaining body balance when performing sports exercises in various conditions remains relevant in sports gymnastics.

Particularly, in gymnastic exercises on rings, the static-dynamic stability of the athlete's body and minimizing the swinging of the rings when performing a given movement program are issues that require more careful study.

It should be noted that the biomechanical structure of the technique of gymnastic exercises on the rings has always been within the focus of both coaches and researchers (Đorđević et al., 2023; Lecocq et al., 2025). Considerable interest in this issue has consistently been demonstrated by specialists in sports biomechanics (Lytvynenko, 2018; Lehmann et al., 2021; Lecocq et al., 2025). This is due to the fact that ring exercises have no direct analogues in sports practice, given the complexity and specificity of the conditions under which the movement program is implemented. Because of the constant increase in competition at the international level, competitive routines are continuously supplemented with increasingly complex technical elements and exercises, which significantly raises the requirements for athletes' coordination abilities and necessitates the search for new approaches in the training process (Malíř et al., 2023). Therefore, it is not surprising that the biomechanical structure of gymnastic exercises on the rings is sufficiently studied and well understood by specialists in this field (Merz et al., 2023; Rosaci et al., 2025; Schärer et al., 2025). However, despite the interest of coaches and athletes driven by the need for continuous improvement of technical elements, the problem of effective balancing in ring exercises remains one of the most fundamental issues. Simultaneously, it is one of the most difficult to resolve in achieving the desired performance outcome.

Both data from specialized scientific literature and the analysis of the competitive performance of athletes of various qualification levels (incuding participants of World Championships and Olympic Games of different years) indicate that the problem of ring oscillations and imbalanced deviations of the athlete's body center of mass relative to the vertical (imbalance of forces and their moments) has been and remains one of the key issues. This problem is closely and inseparably linked to the maintenance of the static-dynamic stability of the body under conditions of mobile support.

Addressing this issue is of particular importance for practicing coaches and athletes, as it enables the improvement of technical mastery and final competitive performance. Consequently, the outlined problem acquires prominent relevance and practical significance.

In our opinion, its solution should be accompanied by the study of the mechanisms of regulation of posture and body position, their formation, and their improvement. This includes, as a component of training, the coordination abilities of the athlete in general and the static-dynamic stability of the body.

Materials and methods

Participants and Organization of Research. Seventeen qualified athletes (I sports category) and ten highly qualified athletes (Honored Master of Sports, Master of Sports of International Class) participated in the descriptive experiment. The duration of the descriptive experiment was four weeks.

The main tasks for gymnasts were to perform large backward rotations on the rings with a focus on achieving the best individual result (minimizing technical errors in accordance with the competition rules) and preventing the rings from swaying in the final position of a handstand. The exercises began and ended in the starting position of a handstand. Each athlete had three attempts. The rest period between each attempt was 5 minutes.

Procedures and Instruments. The registration and analysis of athletes' movements were carried out using the "Contemplas" mobile video recording and analysis system with a resolution of 150 frames per second. The obtained kinematic indicators of the gymnasts' movement technique were used to study the mechanisms of posture regulation as a component of the body's static-dynamic stability. As an integral indicator of the statodynamic stability of the gymnast's body when performing a large backward rotation, we recorded the swinging of the rings in the sagittal plane in the final phase of the movement.

We used the method of quantitative and qualitative biomechanical analysis of gymnasts' movements during the execution of a large backward roll, taking into account the division of their phase structure into four main periods, namely: preparatory actions of the roll, main actions of the roll, implementation actions, and final actions. When applying the method of biomechanical analysis of a large backflip, the sagittal plane was divided into spatial quadrants: the first quadrant – from the initial position in a handstand to the horizontal; the second – from the horizontal to the lower vertical position; the third – from the lower vertical to the horizontal; and the fourth quadrant – from the horizontal to the final position in a handstand. This approach to quantitative and qualitative biomechanical analysis allows the athlete's actions to be classified both in terms of the performance of motor tasks and in terms of the location of the athlete's body in space at different moments in time.

Statistical analysis. Data systematization and statistical analysis were performed using Microsoft Excel 2019 spreadsheets and "Statistica" software (StatSoft, version 12.0). During the processing of quantitative data, the confidence level was 95% (significance level p=0.05).

Results

Analysis of the kinematic structure of the big backflip on rings technique shows a sharp increase in the resulting speed of the athlete's body center of mass from the upper vertical position and its decrease to the moment of the lower vertical, associated with the formation of an external moment of gravity relative to the axis of grip (applied to the athlete's body center of mass). Its value increases in the first quadrant, reaching a maximum in the horizontal position of the gymnast's body. In the second quadrant, the shoulder of gravity decreases as the athlete's body approaches the lower vertical position, which leads to a decrease in the action of the moment of gravity, reaching zero at the lower vertical position..

When the athlete moves from the bottom to the top, the resulting speed of his body's center of mass increases due to the swinging movements of his legs. The magnitude of the gravitational force moment increases in the third quadrant, which has a braking effect on the athlete's body movement. From a horizontal position, the magnitude of the moment of gravitational force decreases, reaching zero at the top vertical position if the movement is performed correctly. The resulting speed of the gymnast's body center of mass also reaches zero.

This general characteristic of motor action is typical for gymnasts of different skill levels.

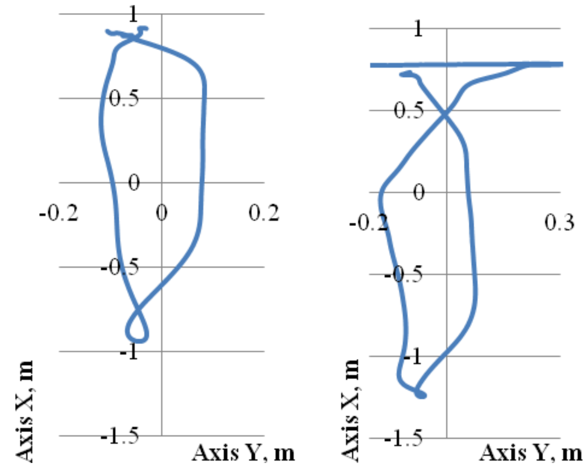
At the same time, analysis of the dynamics of changes in velocity components (in particularly horizontal velocity) indicates the presence of fundamental differences (Table 1).

Table 1. Indicators of the horizontal component of the velocity of the center of mass of gymnasts of different skill levels when performing a large backward rotation on the rings

Periods of the phase structure of a gymnast's movement (spatial quadrants)	statistical data			
	M	Me	Mo	SD
	highly qualified			
First	0,312	0,315	-	±0,031
Second	0,594	0,594	-	±0,026
Third	0,302	0,299	0,298	±0,025
Fourth	0,150	0,151	-	±0,011
	qualified			
First	0,362	0,315	-	±0,021
Second	0,649	0,594	0,654	±0,037
Third	0,486	0,299	0,468	±0,043
Fourth	0,808	0,151	0,745	±0,053

Note: M – the mean of a distribution; Me – the median; Mo – the mode; SD – the squared deviation

The horizontal velocity component of the body's center of mass in skilled gymnasts indicates expressed corrective movements of the athlete in the action phase (third quadrant), which lead to horizontal swinging of the rings in the final part of the movement (in a vertical handstand – fourth quadrant).



a) b)

Fig. 1. Typical examples of the trajectory of the center of mass of gymnasts of different skill levels when performing a large backward swing:

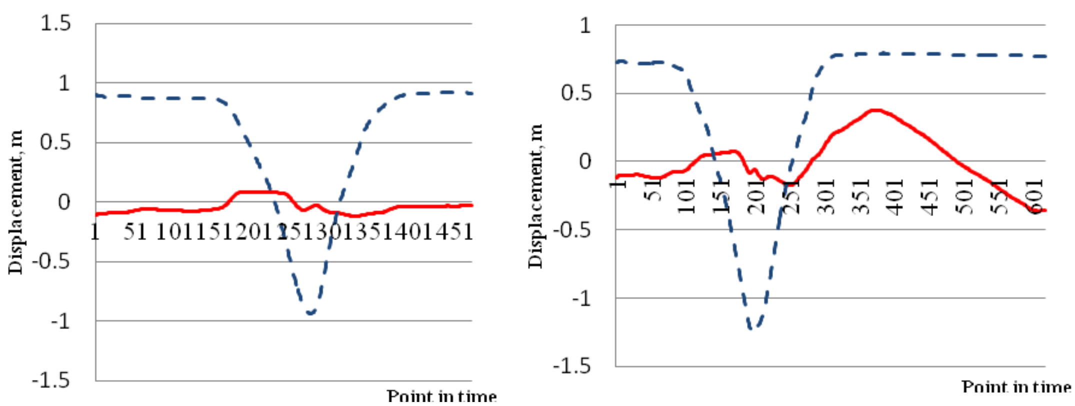
а) – highly skilled athlete (V-v);

б) – skilled athlete (D-ko).

The trajectory of the center of mass of skilled athletes is asymmetrical (relative to the vertical), particularly in the execution phase, where horizontal deviations (from the vertical) are observed, followed by a rather sharp movement in the opposite direction (towards the vertical). Such an asymmetrical trajectory of the body's center of mass (the ratio of the gymnast's descent and ascent) causes the rings to swing (Fig. 1).

The vertical component of the trajectory of the center of mass of the body in gymnasts of different skill levels has the same shape, similar to a parabola.

At the same time, the horizontal component of the trajectory of the body's center of mass in highly skilled athletes shows minimal deviations, not exceeding an average of 0.05–0.07 m from the conditional vertical both on the descent (first and second quadrants) and on the ascent (third and fourth quadrants) (Fig. 2).



а) б)

Fig. 2. Typical examples of the components of the trajectory of the center of mass of gymnasts of different skill levels when performing a large backward swing:

а) – highly skilled athlete (V-v);

б) – skilled athlete (D-ko).

– horizontal;

– vertical;

* – The "-" sign on the graph indicates a change in direction.

In qualified athletes, we observe slight horizontal deviations of the body's center of mass from the vertical during descent, which amount to 0.06–0.1 m. At the same time, during ascent, especially in the fourth quadrant, horizontal deviations exceed 0.15–0.22 m. Thus, the horizontal movements of the athlete's body center of mass on one side of the vertical are not compensated by similar movements on the other side, resulting in the rings swaying (after fixation of the final position of the handstand).

To determine the causes of horizontal deviations, the dynamics of angular movements in the shoulder and hip joints of athletes' bodies were studied (at various moments in time, it is precisely in these joints that the controlling movements are performed).

It should be noted that rigid fixation (absence of dynamic changes in angular indicators) in all joints of the athlete's body is impossible. This is primarily due to a significant change in the gymnast's weight during a large rotation (backward and forward) on the rings apparatus. At the bottom, the gymnast's weight is close to zero, but in the second half of the second quadrant, it increases sharply several times relative to the static weight, which can lead to falls from the apparatus. To smooth out this effect, athletes perform bends in the lumbar region of the torso and extensions in the shoulder and hip joints (on the downswing). This makes it possible to reduce the moment of inertia of the gymnast's body relative to the axis passing through the grip point, the moment of gravitational force acting on the athlete's body (relative to the same axis), and prepare the athlete to perform a swing, which is completed on the approach to the lower part of the body's center of mass trajectory (bending at the shoulder and hip joints). As a result of these actions, the trajectory of the gymnasts' body center of mass (in its lower part) has a loop-like shape, which indicates the absence of an instantaneous stop (primarily in the vertical direction). This would inevitably be accompanied by high values of vertical linear acceleration (upward) and an instantaneous increase in the athlete's body weight (proportional to acceleration). Therefore, horizontal movements of the body's center of mass in this case play a critical role in creating a “softening” effect from the inevitable dynamic impact that occurs in the lower part of the body's center of mass trajectory.

The latter, in turn, can cause the athlete to fall off the apparatus or serve as a factor that leads to technical errors during the lift. In particular, the aforementioned horizontal movements of the center of mass of the body of skilled athletes ultimately lead to the rings swaying.

It should be noted that the shape of the “loop” in highly skilled athletes is more rounded and symmetrical, unlike that of skilled gymnasts. This is evidence of a certain way of distributing effort in the process of overcoming this section of the trajectory, which depends on previous actions and determines subsequent ones.

In skilled athletes, the shape of the “loop” is characterized by expressed asymmetry, large curvature, and insignificant length.

Analyzing the angular movements of the bodies of gymnasts of different skill levels, it was found that skilled athletes tend to perform a more expressed deflection in the lumbar region of the torso and extension of the hips compared to highly skilled athletes. When leaving the starting position, athletes of both skill groups perform a vertical fall while pushing the rings forward, keeping their initial body position virtually unchanged. A characteristic feature for all athletes is the flexion of the lumbar spine with a simultaneous increase in angular movements in the hip joints at the end of the first and second quadrants. At the same time, this leg movement is more pronounced in skilled athletes. Highly skilled athletes also perform these actions, but the angular displacements are smaller in absolute terms. Thus, in skilled athletes at the moment of horizontal (maximum abduction of the rings), the projection of the angle between the thigh and the torso was 205.53±2.832°. In highly skilled athletes, it was within 201.03±2.405°. In the middle of the second quadrant, skilled athletes increase the value to 218.42±2.985°, while highly skilled gymnasts only reach 207.12±3.15°. The maximum values of this angle are observed when approaching the vertical at an angle of deviation of the rings within 5°, which is typical for athletes of different skill levels. At the same time, it is 224.98±1.97° for skilled athletes and 219.27±2.19° for highly skilled athletes. Further, we observe quite active flexion in the hip joints—athletes perform a swinging motion with their legs.

When the rings are positioned above the axis of the cable attachment, the projection of the angle between the torso and thigh in skilled athletes is 214.21±4.56°, and in highly skilled athletes – 192.86±2.45°. The minimum values of this indicator are reached when the angle of deviation of the rings reaches 8°, with the projection of the angle between the torso and thigh being 119.01±3.43° in skilled gymnasts and 122.71±4.71° in highly skilled athletes. The values obtained indicate a more intense (with greater amplitude) swing movement performed by skilled athletes. It should be noted that the movements of athletes in this part of the whole movement are critical, as they determine the characteristics of the final actions. This is explained by the fact that the zone of deviation of the rings from the vertical by 7–9° is the most optimal. At this point, the athlete has a better opportunity to influence the moving support in both the vertical and horizontal directions to change the position and posture of their own body. When the angle of deviation of the rings decreases, the effect of the vertical component of the support reaction force increases and its horizontal component decreases; when it increases, the vertical component is practically absent and the athlete can move the rings in a horizontal direction.

After passing the specified period, all athletes show movement of the lower limbs, in which the angle between the thigh and the torso increases. At the same time, this process is more expressed in skilled athletes. In particular, at the moment of maximum abduction of the rings (the angle of their deviation from the vertical in all athletes is within 13.4–14.5°), the projection of the angle formed by the thigh and torso in skilled athletes is 173.91±2.99°, while in highly skilled athletes this indicator does not exceed 162.73±1.98°. The duration of overcoming this part of the upward trajectory of the center of mass of gymnasts of different skill levels is within the range of 0.14–0.16 s. Thus, in skilled athletes, the angular velocity of the lower limbs relative to the torso (during the analyzed time interval) is significantly higher than in highly skilled athletes (6.862±0.345 rad/s-1 and 4.373±0.215 rad/s-1, respectively).

By the time they reach the top vertical position, highly skilled gymnasts achieve an angle of 178,47±2,77°. Skilled athletes typically exhibit significant extension in the hip joints, which at a given moment in time is 221.80±3.61°. From the moment the athletes reach the maximum abduction of the rings to the moment of the upper vertical, the duration of time in skilled gymnasts is on average 0.41±0.037 s, and in highly skilled gymnasts – 0.53±0.051 s. During this time interval, the angle in the hip joints changes significantly for qualified and highly qualified athletes (47.89±5.58° and 15.74 ±1.39°, respectively). This fact indicates different angular velocities of the lower limbs in the final phase of the exercise. In skilled athletes, it was 2.029±0.235 rad/s-1, while in highly skilled gymnasts, this indicator did not exceed 0.516±0.009 rad/s-1.

It should be noted that the recorded angular displacements are the result of total displacements occurring both in the hip joints and in the trunk sections.

When studying the dynamics of angular displacement changes in the shoulder joints of athletes of different skill levels, certain features should also be taken into account.

Primarily, highly skilled athletes transition from the starting position by pulling the rings forward with a slight bend in the shoulder joints, the angles of which reach values of no less than 174.36±1.84°. In other words, the initial rotation of the athlete's body is performed mainly relative to the axis of the rings grip with their simultaneous horizontal displacement in the direction opposite to the displacement of the gymnast's center of mass.

For skilled athletes, the exit from a stable vertical position is characterized by flexion in the shoulder joints within the range of 153.41±3.49° (with virtually unchanged angular indicators in the hip and knee joints and torso deflection), which also causes a shift in the athlete's center of mass and loss of balance. In this way, gymnasts impart motion to the rings, pushing them away from themselves). When the horizontal displacement of the rings begins, athletes, on the contrary, perform an extension in the shoulder joints. The maximum is observed in the second quadrant after the rings have reached their maximum deviation from the vertical. In skilled athletes, these values are within the range of 222.41±4.69°, and in highly skilled athletes, they do not exceed 207.31±2.48°.

The projection of the angle between the shoulder and torso at the lowest vertical point in skilled gymnasts averages 190.91±5.68°. These values can be explained by significant deflection in the lumbar region of the torso and the deviation of the pelvis from the conditional vertical line; in highly skilled athletes, it is 179.95±1.29°.

After passing the lower vertical, we observe a more intense decrease in this angular indicator, which reaches its minimum at the moment of the next maximum abduction of the rings: in skilled athletes – 73.60±4.21°, in highly skilled athletes – 82.87±2.94°. The time required for athletes of both groups to perform the corresponding movements between the moments considered is within the range of 0.306-0.336 s. Therefore, it can be stated that skilled gymnasts perform more active flexion in the shoulder joints – the angular velocity is 6.165±0.268 rad/s-1, while in highly qualified athletes it reaches 5.538±0.211 rad/s-1.

It is important to note that the movement is mainly performed by bringing the torso closer to the shoulders. At the same time, we note the position of the athletes' torsos relative to the horizontal at the moment of maximum ring abduction. This angle averages 41.32±3.25° for skilled athletes and 51.25±3.01° for highly skilled athletes, meaning that the body of a highly skilled gymnast is closer to the vertical at this moment.

Further angular displacement in the shoulder joints in athletes of different skill levels is accompanied by extension (mainly due to the movement of the shoulders relative to the torso – bringing the rings under the projection of the center of mass of their own body) and the so-called movement of the arms across the sides. In this part of the movement, highly skilled athletes perform the specified extension at an angular velocity of 3.177±0.198 rad/s-1, and skilled athletes – 4.403±0.458 rad/s-1.

The results obtained indicate that skilled athletes perform a large backward rotation with significant angular movements of the biomechanical links in the studied joints, as well as with a more pronounced deflection in the spine sections. This determines the presence of undesirable horizontal movements of the body's center of mass, its corresponding trajectory of movement, and, as a result, the swaying of the rings in the final part of the movement. Highly skilled gymnasts are characterized by more restrained and balanced movements, which are expressed in less expressed angular displacements in the corresponding joints of the athlete's body.

Discussion

The issue of coordination training is one of the least studied areas of sports training. More and more sports training specialists are trying to identify the specific functions of coordination training within technical training. They emphasize the need to define the independent role, tasks, and content of coordination training in the system of athlete training. In our opinion, it is useful for a deeper understanding of the mechanisms of regulating an athlete's body position, which should be considered in clear relation to the conditions of the movement program's implementation, as evidenced by the results of our research (Lytvynenko, 2018).

The static-dynamic stability of the body, as a component of an athlete's coordination abilities, is rightly considered as one of the components of the effectiveness of an athlete's posture regulation, as noted in a number of scientific works (Hrysomallis, 2011; Boloban et al., 2012; Howerton, 2012; Abuwarda et al., 2024). The scientific community is unanimous about the importance and necessity of improving the effectiveness of the body's static-dynamic stability in various sports, which has a positive effect on the technique of motor actions (Howerton, 2012; Litvinenko & Nikitenko., 2018; Ikonomi et al., 2025). Therefore, the development of technologies and programs aimed at addressing these issues is entirely justified. Our research is in line with this opinion. Experts also agree on the need to use modern methods of biomechanical monitoring (Boylen et al., 2025), video analysis, and reverse video communication to improve the effectiveness of motor skill training and motivation to learn (Bouzid et al., 2025), approaches to improve the visual-motor and cognitive abilities of athletes, such as stroboscopic visual training technologies (Jothi et al., 2025), etc., which has also been repeatedly noted in the results of our studies (Boloban et al., 2012; Potop & Cretu, 2015; Lytvynenko, 2018).

At the same time, analysis of scientific works shows that there is a certain inconsistency in this context, since most studies are descriptive in nature and focus on traditional indicators of athlete stability (Litvinenko et al., 2015; Krištofič et al., 2018; Pryimakov et al., 2021). Such information is certainly valuable, but unfortunately, in most cases, it does not reflect the relationship with the mechanisms of posture regulation, the end result of the performed motor action. On the other hand, there are studies aimed at investigating the biomechanics of motor actions in various sports (Litvinenko et al., 2014; Potop & Cretu, 2015; Gamalii et al., 2018). Only in a few studies do we see a combination of body stability conditions with sports techniques and the subsequent development of appropriate technologies to improve their effectiveness (Hedbávný et al., 2013; Kochanowicz et al., 2015; Litvinenko & Nikitenko, 2018; Achilleopoulos et al., 2022; Ikonomi et al., 2025).

We believe that the study of indicators of the body's static-dynamic stability should be considered in terms of its impact on the effectiveness of an athlete's motor skills. This issue is quite complex and requires new approaches, including the use of the most modern biomechanical research methods. In this regard, we proposed to consider the issue of maintaining the athlete's body balance in the context of studying the mechanisms of regulating the athlete's body posture, taking into account the conditions of static-dynamic stability.

Therefore, it is important to consider the conditions for implementing the movement program. Specifically, in exercises on the rings apparatus, the condition of a moving support determines, on the one hand, a relatively large variety of possible movements for the athlete and, on the other hand, their high complexity. The kinematic parameters of a gymnast's movement on the rings are, to a certain extent, similar to those demonstrated by athletes on a rigid support (Hedbávný et al., 2013; Kochanowicz et al., 2015). At the same time, the specifics of the movable support introduce their own peculiarities, thereby affecting both the kinematics of the athlete's movement and, predominantly, its dynamics. Firstly, the requirements for the accuracy of the regulation of the athlete's posture and body position in space are significantly increased. In this regard, his movements must be balanced relative to the vertical axis.

Using this approach, we investigated various mechanisms of static-dynamic stability of the bodies of gymnasts of different skill levels when performing exercises on the rings apparatus. We consider this area to be promising, as its application has allowed us to identify the most effective movement organization and movement guidelines for ensuring the static-dynamic stability of the body when performing exercises on the rings apparatus: constant control of posture, focused primarily on the movement of the pelvis (the area closest to the body's center of mass) and ensuring rational and timely actions of the controlled body segments. This feature is clearly visible during the ascent (third and fourth quadrants), where restrained swinging movements of the lower limbs are performed with an emphasis on the movement of the pelvis, reflected in the trajectory of the athletes' body center of mass. It is the optimal preservation of body posture at different moments in time and balance of forces acting on the gymnast's body, resulting in minimization of unnecessary and uncontrolled swinging of the rings in the final part of the movement. This ensures optimal static-dynamic stability of the athlete.

In the future, it will be equally important to demonstrate the relationship between the technique of the athlete's motor action and the indicators of his statodynamic stability, which will be presented in subsequent publications, considering the research results already presented.

Conclusions

The static-dynamic stability of an athlete should be considered as a multifactorial phenomenon. Therefore, further study of this issue should be based on considering the specifics of the conditions for performing programmed sports movements, while identifying effective mechanisms for regulating body posture and subsequently developing methodologies, techniques, and individual training programs that take these specifics into account.

The study examined the mechanisms of static-dynamic stability of gymnasts of different skill levels when performing exercises on the rings apparatus. In the case of skilled gymnasts, the emphasis in regulating body posture is placed on active changes in the kinematic parameters of the movements of kinetic chains, which play the role of leading mechanisms. In particular, active swinging movements of the lower limbs in combination with significant deflections of the torso.

In highly skilled athletes, these movements (including swinging movements) perform only an auxiliary function. The movements of free and closed kinetic chains (lower and upper limbs) are implemented as a coherent, coordinated, but guided mechanism. The control role is assigned to the connecting link that transmits mechanical impulses. In accordance with the established principles of organizing motor action, the pelvis and the lumbar region of the torso form the key segment that defines the nature of movement. Their specific rotational actions (around the transverse axis of the pelvis and through analogous motion in the lumbar spine) serve as the primary mechanism that determines how the controlled segments (open and closed kinematic and kinetic chains) move in different phases and in line with the purpose of the action, while also maintaining or transmitting force impulses from one segment to another. This mechanism, which ensures the static-dynamic stability of the gymnast's body under conditions of mobile support, is visually less apparent than the active swinging of the lower limbs or the flexion (extension motions of the shoulder joints). However, as our research shows, it plays a crucial and efficient role.

The obtained results indicate that in conditions of mobile support, the stability of the athlete's body is largely determined by the stability of the lumbosacral complex, which plays an important role in ensuring the balance of the whole body. At the same time, the lumbosacral complex should be considered as a part of the body that includes the lower torso and pelvis, which actively interact with the upper torso and thighs.

Conflict of interest

There were no conflicts of interest.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors did not use any generative AI and AI-assisted technologies in the writing process.

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