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Original article

BIOMECHANICAL CHARACTERISTICS OF THE UNDERSWING FROM THE LOW BAR TO THE HIGH BAR ON UNEVEN BARS

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Abstract

Aim. Identification and analysis of the kinematic and dynamic characteristics of the key elements of the underswing movement from the low bar to the high bar on uneven bars in women's artistic gymnastics.

Methods. This study aimed to optimize sports performances on uneven bars through a scientific approach. It involved seven gymnasts aged 12-15, who were members of Romanian national artistic gymnastics team. The analysis focused on exercises performed during the 2017 World Championships in Montreal. Various research methods were employed, including review of existing literature, use of video-computerized methods to analyze the techniques, employing the postural reference points and use of statistical and graphical representation methods. The study identified six key elements within the phasic structure of the underswing from the low bar (LB) to the high bar (HB) on uneven bars. These elements included preparatory movement phases (SF1.1, SF1.2, and SF2), basic movement phases, multiplication of body posture (MP) at maximum height of the center of gravity (GCG) or hip and concluding movement phases (PF1.1 and PF1.2). The angular features of body segments during the underswing were measured using Kinovea software, focusing on the angles between the hip and torso, and between the torso and arms. Anthropometric and biomechanical parameters necessary for the study were processed using the Physics ToolKit program. Kinematic characteristics such as segmental angular velocity and dynamic characteristics like the resultant force (N) were highlighted in the analysis. These findings provide valuable insights for optimizing gymnastic performances on uneven bars, enhancing technique and potentially improving competitive results.

Results. Angular characteristics reveal the segmental angles of the body during various phases of the underswing from LB (low bar) to HB (high bar) on uneven bars. Analyzing these values provides a detailed picture of the positioning and evolution of the segmental angles. Anthropometric and biomechanical parameters that point out the basic moments of the underswing are presented. These parameters, including weight, height with arms stretched overhead, rotational inertia, and segmental movement radii highlight significant variations among athletes. An analysis of angular velocity and resultant force during the execution of the underswing from LB to HB on uneven bars offers a detailed perspective on the dynamics and effort involved in the different phases of the exercise. The results of the correlation analysis revealed the total number of links between the investigated indices, as well as their direction (negative and positive). The degree of connection varied from very weak correlations (42.87%) and weak ones (36.9%) to moderate (19.1%) and strong (1.2%) correlations. Variations occurred in the relations within movements phasic structure and in the specificities of each analyzed index.

Conclusions. Using the video-computerized method in accordance with the method of postural reference points of the movement helped to identify and analyze the kinematic and dynamic characteristics of the key elements of the underswing from LB to HB on uneven bars. This fact can contribute to the improvement of sports performance on this apparatus.

Keywords: women's artistic gymnastics; key elements; angular features; angular velocity; resultant of force; performance.

Introduction

Artistic gymnastics is a competitive branch of gymnastics with a spectacular evolution. Over the years, it has recorded remarkable progress, developing in line with the trends of high-performance sports while maintaining its particularities (Sands, Caine & Borms, 2003).

Currently, there is an increased focus on improving and perfecting gymnastics apparatus to enhance the complexity and diversity of elements for each apparatus in both women's and men's artistic gymnastics. This involves innovations in new elements and expansion of the range of competitions for juniors. For example, the organization of Youth World Championships and Youth Olympic Games can be taken into consideration. These competitions aim to promote a high

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level of difficulty, complexity and athletic mastery, in accordance with the requirements set by the International Gymnastics Federation (FIG, 2017). Through competitive programs intended for young female gymnasts on all competition apparatuses, the goal is to stimulate excellence and continuous development of this sport worldwide (Atiković, Kalinski & Čuk, 2017; Ferreirinha et al.,2010).

Solving the practical tasks of sports training is impossible without analyzing the interconnections between the separate elements of the athletes' movements and comparing them with certain specific characteristics (Adashevskiy et al., 2014).

The biomechanical analysis of movements in gymnastics plays an essential role in understanding the intricate dynamics and optimizing performance in artistic gymnastics. One of the most captivating and technically demanding maneuvers in women's artistic gymnastics is the underswing from the low bar to the high bar on uneven bars. In order to be executed smoothly and efficiently, this movement requires a precise combination of power, coordination and technique.

Understanding the biomechanical characteristics and physiological demands on the body in artistic gymnastics involves accurately assessing the physical effort exerted by athletes during training. From a biomechanical perspective, artistic gymnastics includes a vast variety of movements, which allow for a wide range of connections and combinations to be performed (Brüggemann, 2005).

In recent years, advances in biomechanical analysis techniques, particularly the use of computer-based video methods and motion capture systems, have provided researchers and coaches with powerful tools to identify and understand the key moments of gymnastics movements. By breaking down complex maneuvers into their component parts and analyzing key biomechanical parameters, researchers can gain insights into optimal execution and find areas for improvement.

The main research has focused on the biomechanical analysis of giants, as well as flight elements such as Tkachev, Yager and Shaposhnikova (Murayama, 2021; Mustafa & Abdwahhab, 2020) and dismounts of varying difficulties (Irwin et al., 2014; Kerwin & Irwin, 2010; Manning et al., 2011). Current studies include the biomechanical analysis of indices related to the transfer of technique elements of the giant performed on the high bar and uneven bars (Knoll, Drenk & Krug, 1996; Knoll, 2001; Potop et al., 2014). There are also studies dealing with: the basic techniques of counter movement forward in flight and clear hip circle to handstand on the uneven bars (Huchez et al., 2015, 2016; Petković et al., 2018); mathematical modeling of the biomechanical characteristics of dismounts (Potop, Mihaila & Urichianu, 2016); assessment of various anthropometric indices in men and women correlated with the results of differences in speed and amplitude of movement; biomechanical analysis of swings and tap swings (Sheets & Hubbard, 2008); optimal kinematic characteristics of uneven bars dismounts and biomechanical analysis of the phasic structure of Pak Salto (Forminte et al., 2020, 2022; Sheets & Hubbard, 2009); kinematic analysis as the basis for training strategy (Semenov, Shlyakhtov & Rumyantsev, 2021).

This article aims to explore the biomechanical characteristics of the underswing from the low bar to the high bar on uneven bars. Through a comprehensive analysis of factors such as joint angle characteristics, angular velocity, resultant force, and segmental movement, the study tries to highlight the mechanical principles underlying this movement and explore how variations in technique and individual biomechanics influence performance.

By reaching a deeper understanding of the biomechanics involved in the underswing from the low bar to the high bar, coaches and gymnasts can refine training strategies, adapt technical instructions and ultimately improve performance results. Moreover, insights gained from this analysis can contribute to the development of conditioning programs and injury prevention strategies, for further advance in the field of women's artistic gymnastics.

The *aim of this study* is the identification and analysis of the kinematic and dynamic characteristics of the key elements of the underswing movement from the low bar to the high bar on uneven bars in women's artistic gymnastics.

Methods

The study involved 7 female gymnasts aged 12-15, who were members of the Romanian national artistic gymnastics team. This scientific approach presents a preliminary study meant to optimize sports performance on uneven bars. The analysis of exercises on uneven bars was conducted during the World Championships in Montreal 2017.

Research methods used: review of specialized literature; video-computerized technique analysis method; method of motion postural cues (Boloban & Potop, 2014; Sadowski et al., 2012); statistical-mathematical and graphical representations method.

Within the phasic structure of the underswing from the low bar (LB) to the high bar (HB) on uneven bars, six key elements were identified:

- In the preparatory movement phase (sub-phase 1.1 (SPh1.1); SPh1.2 and SPh2).
- In the basic movement phase, multiplication of body posture (MP) at the maximum height of the center of gravity (GCG) (hips).
- In the closing movement phase, concluding body posture, CP1.1 and CP1.2.

Angular characteristics of body segments were measured using the Kinovea program, considering the key elements within the phasic structure of the movement. The measured angles included: a) angle between thigh-trunk, and b) angle between trunk-arms. The measured parameters included anthropometric and biomechanical aspects necessary for the biomechanical study of the movement (IR - rotational inertia, RM - segmental movement radius). Kinematic characteristics included segmental angular velocity, while dynamic characteristics involved resultant force (N).

Statistical analysis

The statistical processing was conducted using the specialized KyPlot program, version 6.0, developed by KyensLab Inc. (Japan). Descriptive statistics were employed, including mean, standard deviation (SD) and coefficient of variation (Cv %). The Spearman's correlation coefficient was calculated at $p < 0.05$ significance level. The degree of correlation was interpreted as follows: 0.01-0.25 = very weak correlation, 0.26 – 0.5 = weak correlation, 0.51 – 0.75 = moderate correlation, 0.76 – 0.90 = good correlation, 0.91 – 0.99 = very good correlation.

Results

Figure 1 illustrates the key phases of execution technique during the underswing from the low bar (LB) to the high bar (HB) through an underswing from the handstand position (HSP), performed by athlete C.I. at the World Championships in Montreal (Canada), held from October 2nd to October 8th, 2017, during the qualifications.

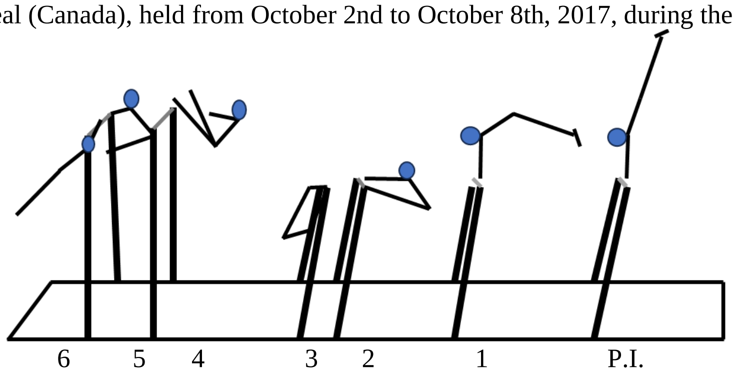

Figure 1. Transition from the low bar to the high bar through an underswing from handstand position (athlete – C.I.)

Note: I.P.: initial position (handstand); 1- subphase 1.1 (SPh1.1); 2 – SPh1.2; 3 - SPh2- launching posture (L.P.); 4 – multiplication of body posture (M.P.); 5 – concluding body posture 1 (C.P.1); 6 – C.P.2

In this regard, 6 key elements within the phasic structure were identified with the help of the Kinovea program: I.P.- initial position HSP done from connection; 1- SPh1.1 - body position in horizontal planche; 2- SPh 1.2 - body position with entry into support with toes; 3- SPh 2- PL – launching body posture before releasing the bar; 4- MP - multiplication of body posture at maximum height of the general center of gravity (GCG); 5- CP1.1 – concluding posture 1 by grasping the HB at the first contact with the bar; 6 - CP1.2 - concluding posture 2 for body extension and balance in hanging position.

Table 1 presents the angular characteristics of body segments during the transition from the low bar to the high bar through an underswing from the handstand position. These measurements were carried out using the Kinovea program, taking into account the key elements of technical execution and the phasic structure of the underswing.

Table 1. Angular characteristics of body segments during transition from the low bar to the high bar through an underswing from handstand position (n = 7)

Statistical indices	PM (degrees)						BM (degrees)		CM (degrees)			
	1		2		3		4		5		6	
	a	b	a	b	a	b	a	b	a	b	a	b
mean	136.4	123.0	33.7	131.4	33.3	139.6	81.0	61.0	99.5	125.4	167.8	154.3
S.E.M.	4.37	3.06	2.39	2.71	1.99	2.73	5.16	5.57	8.91	5.32	5.47	6.96
S.D.	11.57	8.08	6.32	7.18	5.28	7.23	13.66	14.75	23.58	14.08	14.46	18.43
CV%	8.5	6.57	18.74	5.47	15.87	5.18	16.87	24.19	23.72	11.23	8.62	11.94
Min	124	114	21	124	26	127	61	46	69	104	150	130
Max	150	134	40	144	42	147	103	91	140	145	186	182

SEM –standard error mean; S.D. –standard deviation; CV- coefficient of variation, Min – minimum; Max – maximum; PM - Preparatory movement; BM – Basic movement; CM – Concluding movement; 1- subphase 1.1(SPh1.1); 2 – subphase 1.2 (SPh1.2); 3 - SPh2- L. P. - subphase2 – launching body posture; 4 – multiplication of body posture –max. height of GCG – flight phase (MP); 5 – concluding body posture SPh1.1 (C.P.1.1); 6 – CP1.2.; a – angle between thigh -trunk; b – angle between trunk – arms

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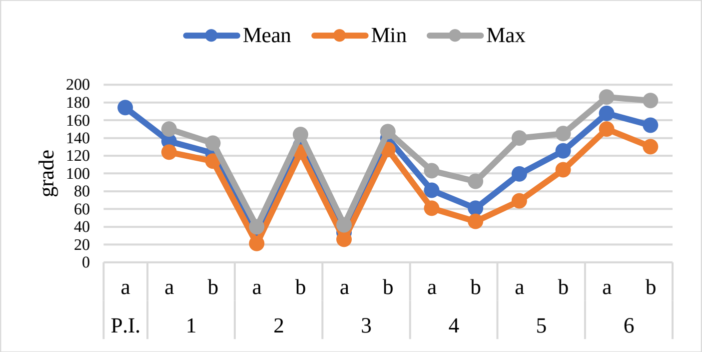

Figure 2. Graph of the segmental angular characteristics relationship between mean and the minimum and maximum values during transition from the low bar to the high bar through an underswing
Note: I. P. - initial position (I. P.); 1- subphase 1.1(SPh1.1); 2 – subphase 1.2 (SPh 1.2); 3 - SPh2- L. P. - subphase 2 – launching posture; 4 – multiplication of body posture – max. height of GCG – flight phase (MP); 5 - concluding body posture SPh1.1 (C.P. 1.1); 6 – CP1.2.

The angular measurements between segments were evaluated for each key element of the technical execution within the phasic structure of the underswing. The measured angles were: a) the angle between thigh and trunk, and b) the angle between trunk and arms. The average results of segmental angular characteristics in the execution of the underswing from the low bar to the high bar are presented in Figure 2.

The analysis of the results presented in Table 1 and Figure 2 highlights the statistical indices ($\bar{x}$; ±S.D.) for the preparatory movement phases. At the body position in SPh1.1, the angle between thigh and trunk (a) is 136.4°; ±11.57°, while the angle between trunk and arms (b) is 123.0°; ±8.08°. In SPh1.2, at the entry into support on toes, the angle (a) is 33.7°; ±6.32°, and the angle (b) is 131.4°; ±7.18°. In SPh2-LP, the launching body posture before releasing the bar, the angle (a) is 33.3°; ±5.28°, and the angle (b) is 139.6°; ±7.23°. In the basic movement phase (flight phase), at the body multiplication posture at the maximum height of the GCG (hips), the angle (a) is 81.0°; ±13.66°, and the angle (b) is 61.0°; ±14.75°. In the concluding posture phase (CP), at the body position while grasping the high bar (HB) at CP1.1, the angle (a) is 99.5°; ±23.58°, and the angle (b) is 25.4°; ±14.08°. In the final posture CP1.2, in hanging position, the angle (a) is 167.8°; ±14.46°, and the angle (b) is 154.3°; ±18.43°.

Table 2 shows the anthropometric and biomechanical parameters necessary for the study of the underswing from the low bar to the high bar. The data were processed using the PhysicsToolKit program. There were highlighted the athletes' weight and height with arms raised above head, the rotational inertia (IR) and segmental movement radius (RM) of the hands, GCG (general center of gravity), shoulders and arms, automatically calculated by the program.

Table 2. Anthropometric and biomechanical parameters necessary for the biomechanical study of the transition from the low bar to the high bar through an underswing (n = 7)

Statistical indices	Weight (kg)	Height with arms raised above head (m)	IR ($kg \cdot m^2$)	Radius of segmental movement (m)			
				Toes	GCG (hip)	Shoulders	Arms (hand)
mean	38.86	1.74	118.5	1.131	0.999	0.841	0.671
SEM	1.41	0.02	7.25	0.03	0.02	0.01	0.01
S.D.	3.74	0.06	16.19	0.09	0.04	0.03	0.03
CV%	9.63	3.42	16.18	8.15	4.25	3.17	4.46
Min	34.5	1.67	96.3	0.991	0.937	0.798	0.634
Max	46.2	1.83	154.8	1.256	1.059	0.878	0.714

IR – rotational inertia; GCG – general center of gravity (hip joint)

The analysis of the results presented in Table 2 reveals the individual values and statistical indices, the mean and the standard error (±S.D.). In the case of the weight, the values are 38.86; ±3.74 kg; for height with arms raised above head: 1.74; ±0.06 m. These indices are necessary for the calculation of rotational inertia (IR), which is 118.5; ±16.19 $kg \cdot m^2$. The segmental movement radius (RM) of the hands is 1.13; ±0.09 m; for GCG, it is 0.999; ±0.04 m. As for shoulders, it is 0.841; ±0.03 m and for arms, it is 0.671; ±0.03 m. Analyzing the individual values of the indices, significant differences are observed as follows: the RM of the hands varies by 0.267 m (difference between maximum and minimum), the RM of GCG (hips) varies by 0.122 m while the RM of shoulders and arms each varies by 0.08 m. These differences emphasize the importance of the toes position and the raising of the GCG to the maximum height of the flight, which influences the execution of the concluding phase (grasping the high bar, HB).

Figure 3 depicts the trajectories of body segments during the execution of the transition from the low bar (LB) to the high bar (HB) through an underswing, performed by athlete C.I. on uneven bars; the starting point is the low bar. The graphical representation analysis of the trajectories of body segments (Xm, Ym) highlights the following matters, depending on the segment involved and its respective position (key element): in SPh1.1, the relationship between shoulders, GCG and toes should be horizontal. At SPh1.2, the moment of supporting on soles is related to GCG below the bar (while falling). In SPh2-LP, the moment when GCG moves upwards is after the clearance vertical and the horizontal plane related to the bar. MP shows the maximum height of GCG in the flight phase, considering the position of the feet, shoulders and arms. In the CP1.1, the position of the shoulders and feet at the moment of grasping the HB can be observed. In the CP1.2, it is highlighted the final moment of continuing the momentum after grasping the bar.

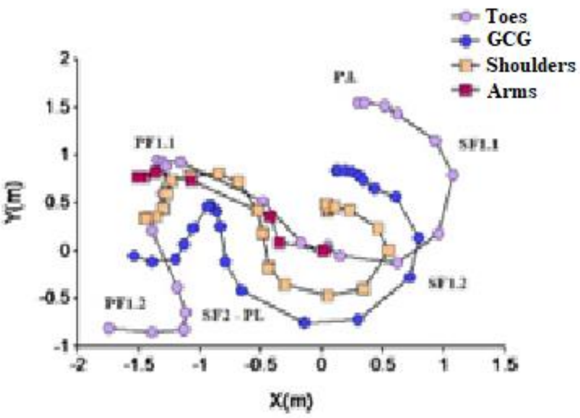

Figure 3. Trajectories of body segments during execution of the transition from LB to HB through an underswing (athlete C.I.)

Figure 4 presents the results regarding the angular velocity of body segments during the execution of the transition from the low bar (LB) to the high bar (HB) through an underswing, performed by athlete C.I. on uneven bars.

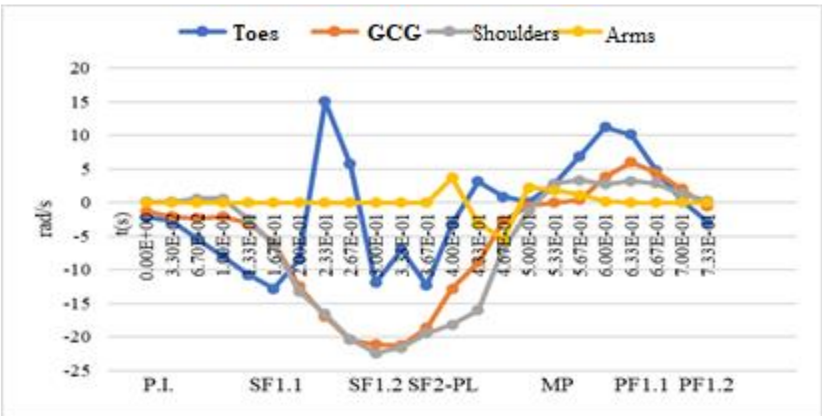

Figure 4. Results of angular velocity of body segments in transition from LB to HB through an underswing (athlete C.I.)

The analysis of angular velocity values presents the values as follows: during the preparatory phase: SPh1.1, the angular velocity at toes is higher, reaching -12.848 rad/s. At SPh1.2, the shoulders enter into action with -22.384 rad/s and GCG with -21.129 rad/s. In SPh2-LP, the angular velocity slows down slightly before detachment from the bar; it is -19.451 rad/s for the shoulders and -18.638 rad/s for GCG. During the flight phase, at the maximum height of GCG, it is observed that the shoulders and toes have almost equal values: 2.792 rad/s for toes and 2.799 rad/s for shoulders, while GCG is 0.00 rad/s (stop). In the concluding phase CP1.1, the angular velocity is higher at the level of GCG, with 4.846 rad/s, and at the level of toes, with 4.821 rad/s, as a result of completing the bar grasping action.

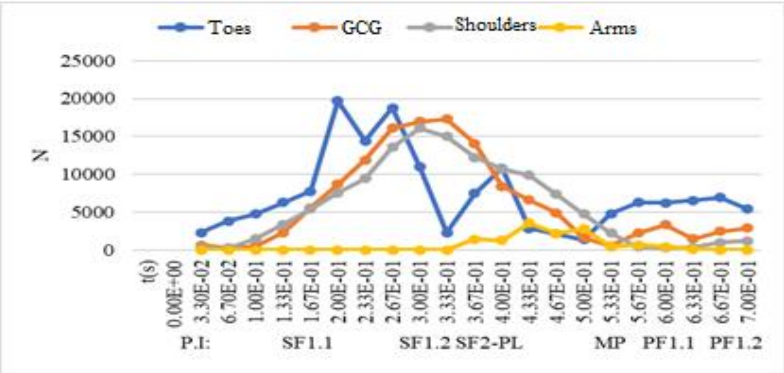

Figure 5. Values of the resultant force at the level of the body segments during the transition from LB to HB through an underswing (athlete C.I.)

Figure 5 presents the values of the resultant force at the level of body segments during the execution of the underswing from the low bar (LB) to the high bar (HB), performed by athlete C.I. on uneven bars.

The analysis of the resultant force values points out the following matters: during the preparatory phase, at SPh1.1, the highest value is at the toes, with 7730 N.

In SPh1.2, the maximum values are at GCG, with 17000 N, and at the shoulders, with 16100 N.

At SPh2-LP, the force at the level of GCG decreases up to 1410 N. In the basic phase MP, the force at toes level is 4790 N; at shoulders level the force is 2240 N. In the concluding phase CP1.1, the force at toes is 6910 N, followed by GCG with 2420 N, shoulders with 986 N and the arms with the lowest value of 70.24 N before grasping the bar. These values reflect the dynamics of the forces exerted on body segments in different phases of the technical execution.

Table 3 shows the results of the correlation analysis between the indices of segmental angular characteristics at each key moment of the technique and the anthropometric indices, IR and RM, during the transition from LB to HB through underswing.

The results of the correlation analysis reveal 84 connections between the investigated indices, where 52.4% are negative correlations and 47.6% are positive ones. Regarding the degree of correlation between the analyzed indices, it was observed that 42.87% are very weak correlations (R=0.01-0.25), 36.9% are weak correlations (R=0.26-0.5), 19.1% are moderate correlations (R=0.51-0.75) while 1.2% are strong correlations (R=>0.76).

Regarding the relationship between indices within the phasic structure of the movement, the following matters were observed. Out of the total number of correlations, in the preparatory movement, 7.14% are moderate connections, 15.5% are weak and 27.4% are very weak. In the basic movement there are 6.0% moderate connections, 4.7% weak, and 6.0% very weak. In the concluding movement 6.0% are moderate connections, 16.7% are weak, and 9.5% are very weak.

Table 3. Results of correlation analysis between the angular characteristics of body segments and anthropometric indices, IR and RM in the transition from low bar to high bar through an underswing (n = 7)

Indices	**1**		**2**		**3**		**4**		**5**		**6**	
	a1	**b1**	**a2**	**b2**	**a3**	**b3**	**a4**	**b4**	**a5**	**b5**	**a6**	**b6**
x1	-0.48	0.61	0.03	0.09	-0.03	-0.13	-0.46	-0.24	0.25	-0.35	0.31	-0.29
x2	-0.18	0.16	-0.12	0.11	-0.13	-0.24	-0.57	-0.34	0.57	**-0.76***	0.38	0.08
x3	-0.37	0.43	-0.02	0.11	-0.05	-0.20	-0.54	-0.29	0.40	-0.52	0.35	-0.17
x4	0.58	-0.26	0.50	-0.50	-0.02	0.32	0.04	0.12	-0.01	0.60	0.17	-0.32
x5	0.66	-0.54	0.24	-0.27	-0.19	-0.02	-0.42	0.05	0.37	0.29	0.15	-0.26
x6	0.40	-0.43	0.15	-0.09	0.61	-0.38	-0.61	0.16	0.46	0.28	-0.21	-0.42
x7	0.52	-0.24	-0.04	0.27	0.37	0.17	-0.58	0.62	0.13	0.62	-0.29	-0.68

phasic structure: 1-3 – preparatory movement, 4 – basic movement, 5-6 – concluding posture; a – angle between thigh -trunk; b – angle between trunk – arms; x1 – Weight (kg), x2 – height with arms raised above head (m), x3 – IR (kg·m^2), RM (m) – x4 (Vârfuri), x5 – (GCG), x6 (Shoulders), x7 – (Arms).

Regarding the relationship between the analyzed indices, the value of 14.3% out of the total correlations was noticed. Comparing each index, the following observations can be made:

- x1: 1.2% are moderate connections, 6.0% are weak and 7.1% are very weak.
- x2: A strong correlation (R=-0.76, $p<0.05$) was observed, representing 1.2% of the total correlations, between the height with arms stretched up high and the angle between the trunk and arms (b5) in the final position, in the concluding posture phase. Additionally, 2.4% are moderate connections, 2.4% are weak and 8.3% are very weak.
- x3: 2.4% are moderate connections, 6.0% are weak ones and 6.0% are very weak.
- x4: 2.4% are moderate connections, 6.0% are weak ones and 6.0% are very weak.

- x5: 2.4% are moderate connections, 6.0% are weak ones and 6.0% are very weak.
- x6: 2.4% are moderate connections, 7.1% are weak ones and 4.7% are very weak.
- x7: 6.0% are moderate connections, 3.6% are weak ones and 4.7% are very weak.

All these connections highlight the influence of anthropometric parameters, IR and RM on the technical execution in each phase of the movement.

Discussions

This study intends to identify the key moments of the technique used in exercises on uneven bars. For this purpose, the method of motion postural cues was applied and a biomechanical analysis was carried out by means of the video computerized method. The kinematic and dynamic structure parameters of the exercises on uneven bars were assessed during their performance by 12-15-year-old gymnasts.

The biomechanical analysis focuses on the technical elements consistent with the requirements of the International Code of Points for uneven bars (FIG, 2017), considering the content, construction and composition of the exercise.

The analysis of the results obtained in the preliminary research reveals the importance of identifying the technique key moments in the exercises on uneven bars. By using the Kinovea program, six key elements were identified within the phasic structure of the transition from the lower bar (LB) to the upper bar (UB) through an underswing from handstand position (HS), performed by the athlete C.I. during the qualifications for the World Championships of Montreal in 2017 (Figure 1). These key elements are essential for the understanding and detailed analysis of the technique used in exercises on uneven bars. Thanks to these elements, researchers can assess the correctness and efficiency of exercise execution, identifying areas for improvement or optimization in order to maximize the performance of athletes. Also, these key moments provide a solid foundation for training and teaching, allowing coaches to focus on critical aspects of technique and strategically improve the performance of the athletes.

The analysis of the results presented in Table 1 and Figure 2 highlights the angular characteristics of body segments during the transition from the low bar to the high bar through an underswing from handstand. These measurements were done using the Kinovea program, considering the key elements of technical execution and the phasic structure of the underswing. The analysis of statistical indices ($\bar{x}$; ±S.D.) shows the variation of segmental angles in the various phases of the preparatory movement during the underswing from the low bar to the high bar. This analysis reveals that the segmental angles generally meet the technical requirements of execution. There are minimal variations between measurements and a uniform distribution of standard deviations, reflecting consistency in execution and control over movements in each phase of the exercise. These results provide a detailed insight into the angular modifications of body segments in different phases of execution, which can be valuable for understanding and improving the technique of exercises on uneven parallel bars.

The analysis of anthropometric and biomechanical parameters, presented in Table 2, points up significant variations among athletes regarding weight, height with arms stretched up high, rotational inertia and segmental movement radii. These differences suggest that the position of the toes tips and the maximum height of the center of gravity (GCG) influence the execution of the exercise final phase, grasping of the high bar (HB).

The analysis of the graphical representation of body segment trajectories during the execution of the transition from the low bar (LB) to the high bar (HB) through an underswing, as shown in Figure 3, highlights important aspects related to the positioning and movement of the athlete in each key element of the execution.

The analysis of the angular velocity values and force resultant during transitioning from the low bar (LB) to the high bar (HB) through an underswing, as depicted in Figures 4 and 5, offers a detailed perspective on the movement dynamics and the effort exerted on body segments in different phases of the exercise.

Regarding angular velocity, it is observed that it varies according to the movement phases. In the preparatory phase, angular velocity is higher at toes level in SPh1.1, indicating intense preparation for the movement execution. In SPh1.2, the involvement of shoulders and GCG brings a significant acceleration of the movement. Then, in SPh2-LP, angular velocity slightly decreases before the release of the bar. In the flight phase, angular velocity at the GCG level is almost zero, reflecting the peak moment of the movement. Finally, in the concluding posture phase (CP1.1), angular velocity is higher at the GCG and toes levels, demonstrating the intense action for the completion of the bar grasping movement.

Regarding the force resultant, it shows the distribution and intensity of forces exerted on body segments. In the preparatory phase, maximum values are recorded at the level of toes, shoulders and GCG levels, reflecting the intense effort for movement preparation. In the basic phase (MP), force is more concentrated at toes and shoulders levels, indicating body support and balance during the flight movement. In the concluding phase, force is mainly distributed at toes and GCG levels; the low values at arms level highlight the completion of the movement and preparation for grasping the bar.

Generally, the analysis of these aspects provides a deeper understanding of the dynamics and stresses exerted on the body during the execution of transition from LB to HB through an underswing.

The results of the correlation analysis revealed the total number of connections between the investigated indices, as well as their direction (negative and positive), with the degree of correlation ranging from very weak (42.87%) and weak (36.9%) to moderate (19.1%) and strong (1.2%), with variations in the relationships within the phasic structure of movements and specificities for each analyzed index. The biomechanical analysis of uneven bars routines monitors also the tools (software), the parameters and the indices correlated within the research, regarding the biomechanical characteristics of dismount techniques and the performance (Potop, Timnea & Stanescu, 2017). Other matters addressed by the specialists in this field were: the biomechanical characteristics of rotational movement transfer (Potop, Grigore & Timnea, 2014), the impact of using specialized programs on landing stability (Gavojdea, 2015), the biomechanical analysis of the structural phase in Pak Salto (Forminte et al., 2022) and the mathematical modeling of the dismounts biomechanical characteristics (Potop, Mihaila, & Urichianu, 2016). There were also studied the influence of physical training on technical execution (Potop & Cretu, 2018), the kinematic characteristics of the dismounts (Forminte, Potop & Micu, 2020), the improvement of the Jaeger salto technique based on biomechanical indicators (Potop, Cretu & Timnea, 2017), the role of auxiliary equipment in studying the kip on uneven bars (Bozhinova & Petrova, 2022) and the development of dismount technique key elements (Potop, Stanescu & Cretu, 2017).

The analysis of this information could highlight aspects such as the influence of different movement elements on the kinematics and dynamics of execution, as well as potential correlations between these aspects and athletic performance or the risk of injury. Additionally, one could examine how to use these data to improve training techniques and performance of athletes.

Conclusions

Using the video-computerized method in conjunction with the motion postural cues method enabled the identification and detailed analysis of the kinematic and dynamic characteristics of the transition from the low bar to the high bar through an underswing in women's artistic gymnastics. This approach can significantly contribute to optimizing performance in uneven bars.

Identifying and analyzing the key moments in the technique of uneven bars exercises are essential for understanding and improving the performance of the gymnasts. These aspects provide researchers and coaches with a detailed perspective on the correct and efficient execution of movements, while also ensuring a solid basis for optimizing the training and instruction process.

The detailed analysis of angular characteristics of body segments while transiting from the low bar to the high one through an underswing highlights a precise movement control and an adequate compliance with technical requirements. This analysis offers important information for understanding and improving the technique used in the exercises on uneven bars.

The analysis of anthropometric and biomechanical parameters reveals significant variations among athletes, emphasizing the importance of individualizing training depending on the specific physical characteristics of each athlete. These differences underline the importance of factors such as the position of the toes tips and the maximum height of the center of gravity in influencing the correct execution of the final phase of the exercise.

Detailed analysis of angular velocity and force resultant shows the appropriate adaptation and distribution of the effort throughout different phases of the movement, expressing precise control and technical efficiency. These findings prove the importance of balance and coordination during this complex exercise.

The correlation analysis between the anthropometric indices, IR, RM and the segmental angular characteristics emphasized variations in the degree of correlation, ranging from very weak and weak correlations to moderate and strong ones, with variations in relationships within the phasic structure of movements and specificities for each one of the analyzed indices.

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