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Biomechanical characteristics of transfer in the rotational movements on uneven bars

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Keywords: artistic gymnastics, kinematics, dynamics, difficulty, technique, performance.

Abstract. This paper tries to highlight some biomechanical characteristics of the transfer in the rotational movements on uneven bars in women's artistic gymnastics. This scientific approach led to a study conducted during the Masters National Championships from 16th to 18th of October 2012, in "Nadia Comaneci" Polyvalent Hall of Onești. The study involved 7 gymnasts belonging to junior training team of Deva, aged 12 to 15. The following methods have been used in this research: method of bibliographic study, method of pedagogical observation, method of biomechanical video analysis using Kinovea and Physics Toolkit programs, experiment method, statistical method (KyPlot) and the method of graphical representation (Excel). The analysis of difficulty values of the technical elements on uneven bars as per the Code of Points emphasizes the dynamics of the vertical and horizontal transfer, depending on the category / type of the movement and the difficulty group. The results of the study highlights how the transfer is made throughout the routines on uneven bars in terms of kinematics and dynamic characteristics of the key elements of sports technique during the rotational movements. The efficient use of the postural orientation method based on the biomechanical analysis of the rotational movements on uneven bars showed the kinematic and dynamic characteristics of the key elements of sports technique according to the performances achieved in competition.

Introduction

At the present moment, artistic gymnastics has recorded remarkable progresses, highlighting the fact that it develops in accordance with the trends of performance sport, but it has its specific features too, such as: increase of sports mastership, increase and rivalry of competitive programs, processing of new complex routines, sports mastership that reaches virtuosity; improvement of components that provide the training of high classification gymnasts. In the case of the uneven bars, the main development tendencies are the following ones: intensive development of the large swings on the high bar; intensive increase of the difficulty of dismounts and of other movements executed from large swings; increase of the level of difficulty of connection movements, elements and links; development of difficult mounts on apparatus depending on the type of supported and acrobatic saltos [1, 2, 3, 4].

Thus, the technique is represented by a system of specific motor structures rationally and economically built, in order to obtain maximum efficiency in competition. The analysis of technique highlights the following components: *technical element, technical procedure, style and basic mechanism* [5]. The effective learning, in different stages of technical training, can be provided only if the learning stages and their content are closely related to efficiency criteria [6]. Analyzing the technique of gymnastics exercises, in terms of bio-mechanical positions, the "arithmetical" entry is used, involving operations of improvement of the concrete matters [3].

In conformity with the requirements and the specific character of women's artistic gymnastics apparatus, the elements on uneven bars can be divided into several structural groups, defined not only according to their execution way, but also according to their purpose, namely: handstands, hip circles (small and big), free passing over bars, saltos and re-grips, simple switches on longitudinal axis or made during different basic movements, transitions from one bar to another, mounts and dismounts [1, 7, 8].

According to the Code of Points, art.11, in terms of content and structure of the routine on uneven bars, a maximum number of 8 elements with the highest value shall be taken into consideration for the Difficulty Value (VD), including the dismount too, representing a variety of the following categories of elements [9, p.41]: 1) rotations and momentum (backward and forward giant, momentum and clear hip circle to handstand, stalder backward/ forward and piked rotation backward/ forward; 2) flights (flight from high bar and gripping the low bar (or vice versa), counter flight over bar, passing, connections and saltos).

The various movements that can be used on the high bar and on uneven bars in artistic gymnastics can be divided into the main exercises having as structural sign the working position on apparatus that highlights the typical movements for each working position and movements group with the same rotation structure. Among the basic and profile routines on these two apparatus, we can refer to movements of large rotation type, movements of salto, flight and release type [3, p.177].

Regarding the conceptual and methodological modern aspects on uneven bars, Bibire M. & Dobrescu T. (2008), present the theoretical and methodological foundations of the special physical training and technical elements learning on uneven bars, the methodology of creation of the routines for competition, the learning methods and the typical mistakes [7].

In artistic gymnastics, the learning of technique reaches high degrees of complexity and is based on "closed" nature motor skills ("Closed skill") [10]. In terms of biomechanics of the rotational movements technique in artistic gymnastics, there are elements on uneven bars and on high bar in which the motor activity is of high dynamism apparently, but in reality the muscle activity that ensures these movements is predominantly static, necessary to achieve a high tonus and to maintain some body postures [11, 12]; the main characteristic of the swing movements is the use of inertia while moving the body to balance the interactions of the internal and external forces [13].

"Biomechanical researches in artistic gymnastics can be performed using both biomechanical methods and methods taken from other fields of knowledge (pedagogical, mechanical, physiological, psychological, medical ones, etc.), mainly intended to highlight the features of movement on various apparatus by selecting the means of data recording, processing and analysis" [14].

Several criteria can be used for splitting gymnastics elements into parts, such as pedagogical, psychological, physiological, biomechanical criteria, etc. The increase of objectification level goes from the pedagogical criteria towards the biomechanical ones. That is why the biomechanical criteria are used for dividing the gymnastics elements into parts. Thus, the technical structure of gymnastics elements contains three levels – *periods, stages and phases* [15].

In the last two decades of the 20th century, computer technology has advanced enormously so that the biomechanical analysis has become a routine problem whose performance depends not only on the hardware-software quality but on their costs implicitly. The computer cannot yet and probably will never be able to automatically interpret the biomechanical movements because the optimization criteria are not always of biomechanical nature; they are also of human nature, by rules and conventions [16].

The current concerns in the scientific research on the biomechanics issues in artistic gymnastics and the features of the rotation exercises refer to the latest classification made by Bruggmann G.P. in 1994 [17], taken over from Hochmuth and Marthold, 1987, quoted by Crețu, M, et al, 2004 [13]; he groups the gymnastics movements in the following categories:

- releases and impetus on solid and elastic surfaces (floor, vaults, beam, parallel bars, uneven bars and high bar);

- rotations in vertical plane around a fixed or mobile axis situated in horizontal plane (high bar, uneven bars and rings);
- rotations in horizontal plane around a fixed axis situated vertically (circles on pommel horse);
- rotations in free flight (floor, simple and double saltos, twist saltos, elements of release and re-grip (high bar, parallel bars, uneven bars and dismounts off high bar, uneven bars, rings);
- landing – dismounts off all apparatus and difficult elements on floor and beam.

Regarding the general bases of sports exercises learning, professor J.K. Gaverdovskij, (2007, p.175), in his monograph "Learning sports exercises", in Part II, chapter on sports technique of exercises – swinging and supported rotations, presents the biomechanical characteristics of the rotations around horizontal axes, the rotations technique and rotations around the vertical axis [18].

According to V. Potop (2007), the transfer of motor skill in the process of gymnastics exercises learning is regarded as an instrument of optimization of the *didactical, pedagogical, psychological, bio-mechanic* processes based on transfer and the content of the education of motor abilities, highlighting the technical mistakes that were hidden in various stages of gymnasts' sports training. In the process of technology transfer, the character with tasks of solving, influencing and/or interdependence is very important. Gymnastics exercises' learning highlights the *vertical transfer* – algorithmic sequence of mastering the exercises with increasing difficulty of the same profile or different one. The author also highlights the achievement of the *horizontal transfer* throughout the process of gymnastics exercises learning [19].

The review of specialized literature certifies the importance of the research on gymnastics exercises technique and its learning, taking into account the body postures and positions. In connection with this fact, V.N. Boloban and E.V. Biriuk (1979) propose the use of the movement postural orientation method for studying the technique of gymnastics sports branches [20]. The concept and methodology of using this method by studying the papers have been perfected during the recent years [21 - 26, etc.].

However the biomechanical approach of transfer technology in artistic gymnastics, especially the rotational movements performed on uneven bars, has not been studied yet. Therefore we proposed to carry out this research, so important and real in performance artistic gymnastics.

Material and method

The purpose of the paper is to highlight the biomechanical characteristics of the transfer in the rotational movements on uneven bars at the level of junior gymnasts 12 to 15 years old.

Hypothesis of the paper. We consider that the use of movement postural orientation method by means of the biomechanical analysis of the routines on uneven bars will emphasize the kinematic and dynamic characteristics of the key elements of sports technique, the modality and directions of achieving the transfer in accordance with the performances obtained in competition.

This scientific approach led to a study conducted during the Masters National Championships from 16th to 18th of October 2012, in "Nadia Comaneci" Polyvalent Hall of Onești. The study involved 8 gymnasts belonging to junior training team of Deva, aged 12 to 15.

The research used the method of bibliographic study, the video computerized method by means of Physics ToolKit program; the method of graphical representation – Excel and the "KyPlot" statistical-mathematical processing. Recording was done with a Panasonic video camera of 50 Hz and a capture card with Pinnacle studio 9 software. The biomechanical analysis was performed using the off-line markers-free program called Physics ToolKit Version 6.0, which can quantitatively describe, by means of kinematic and dynamic features, the rotation trajectory of the pairs shoulder - hip and of the general rotation in the coordination system of the bar, the center of gravity of the biomechanical system represented by the athlete.

During this research we monitored gymnasts' performances on uneven bars in terms of content and construction of the exercise; for the biomechanical analysis, we have selected the following technical elements: Clear hip circle to handstand; Giant circle bwd with 1/1 turn (360°) to

handstand; Gienger Salto; Jaeger-Salto and dismount; each exercise has the key elements specific to sports technique, divided into phases, sub-phases, parts and postures (LP - launching of the body posture; MP – multiplication of body posture and CP - concluding body posture, return to the initial posture or continuation with another exercise [21].

Results

Table 1 shows the means of anthropometric and biomechanical indicators of junior gymnasts 12- 15 years old, necessary for the biomechanical analysis of rotation movement on uneven bars.

Table 1. Means of anthropometric and biomechanical indicators of junior gymnasts 12- 15 years old, necessary for the biomechanical analysis of rotation movement on uneven bars

TE	N	W., *(kg)*	HwAU, *(m)*	I.R., *(kgm^2)*	R.M.*(m)*				
					Toes	GCG	KJ	SJ	Arms
Hip circle	7	36.00	1.87	127.05	1.382	0.716	-	0.575	-
Giant 360°	5	36.92	1.88	132.11	1.65	0.94	-	0.50	-
Jaeger salto	2	40.4	1.91	147.38	1.603	0.952	-	0.585	0.252
Gienger salto	2	35.8	1.88	126.82	1.47	0.97	-	0.61	0.17
Dismount	6	35.6	1.86	124.46	1.45	1.92	1.63	1.187	-

Note: N. – number of subjects, W. – weight, HwAU – height with arms up, I.R. – inertia of rotation, R.M. – radius of segments movement, GCG – general center of gravity, KJ – knee joint, SJ – Shoulders joint, Mean –arithmetical mean, SEM –standard error of the mean.

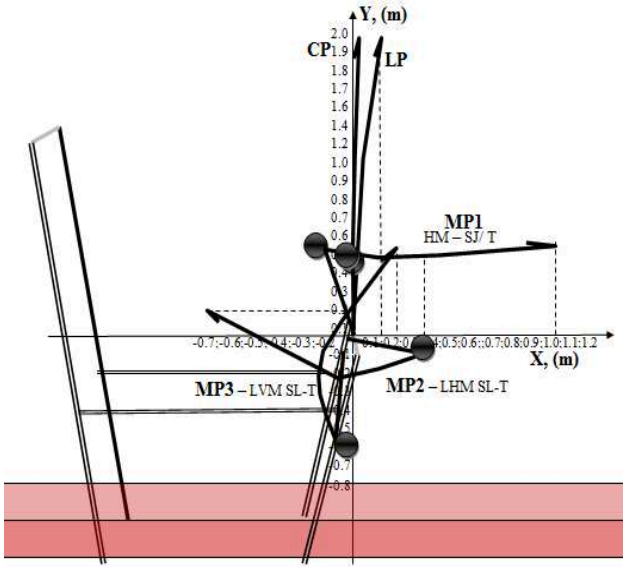


Fig.1. Clear hip circle to handstand on the low bar of uneven bars (S.Ș.)

Note: LP – launching of the body posture; MP1 - HM – SJ/ T- horizontal momentum of shoulders joint and toes relationship; MP2 - LVM –SJ-T - low vertical momentum; MP3 - LHM – SJ/ T – low momentum of shoulders joint and toes relationship, Descen. – Descending, Ascen. - Ascending, MP – multiplication of posture; CP – concluding body posture.

Figure 1 shows a clear hip circle to handstand executed by gymnast SS on the low bar; we can notice the body segments trajectories and the key elements (KE) of sport technique in accordance with the momentum of low vertical, the horizontal of movement descending and ascending phase (MP1, MP2, MP3) and the concluding body posture (CP) - steady position in handstand.

In figure 2 and 3 are shown the values of the mean of force and angular velocity of body segments (G.C.G., Toes and Shoulders joint) at clear hip circle to handstand on the low bar of uneven bars.

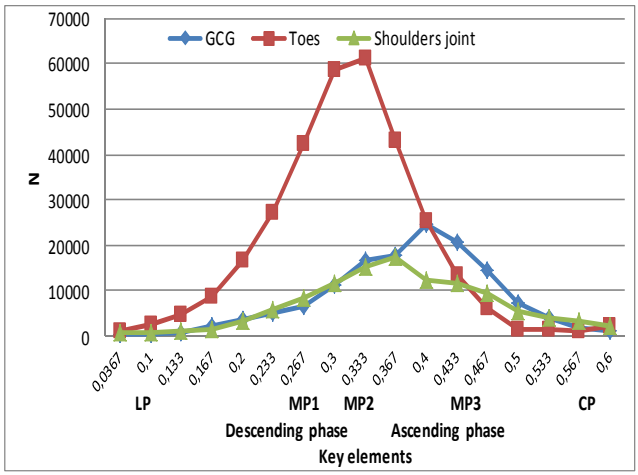


Fig.2. Results of the mean of body segments force at clear hip circle to handstand on the low bar of uneven bars

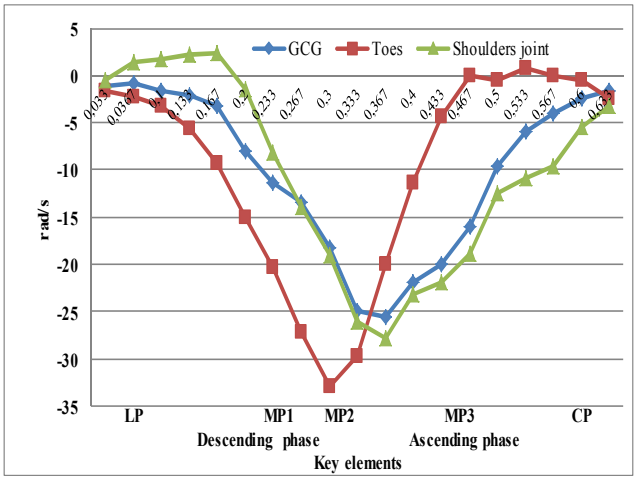
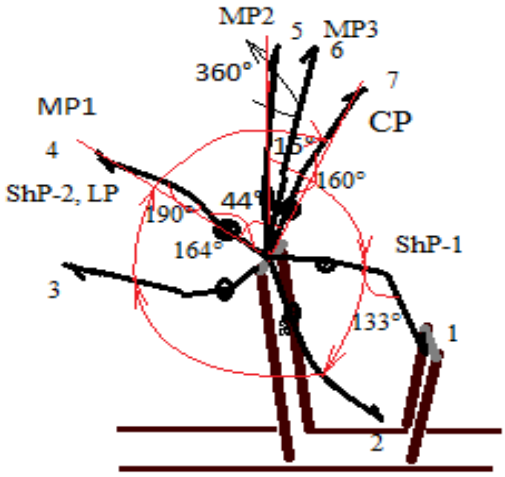


Fig.3. Results of the mean of angular velocity of body segments at clear hip circle to handstand on the low bar of uneven bars



Note: ShP1- sub-phase 1 of the preparatory movement (MP) passing over low bar (BI); 2-3 – intermediate sequences of MP, ShP2-LP – sub-phase 2 – launching posture for turn, MP1-3 – multiplication of body posture by 360°turn ; 7 – CP – concluding posture.

Fig.4. Giant with turn twist 1/1 (360°), SS

Figure 4 presents the phasic structure of the giant with turn twist 360° performed by the athlete SȘ, in terms of key elements of sports technique on the high bar of uneven bars.

Table 2. Biomechanical indicators specific to the Giant with turn twist 1/1 (360°)

Full name	ShP-1, (degrees)	ShP-2 LP, (degrees)		CP – hstd, (degrees)	Directions of turn	Turn 360° hstd	
	Hip	SJ	Hip	Hip		Initial	Final
TP	116	127	164	141	Left	56	47
BA	126	145	165	131	Right	45	34
OAM	121	154	203	167	Left	54	30
SS	133	164	190	160	Left	44	15
TD	163	175	169	163	Right	36	37
Mean	**131.8**	**153**	**176.2**	**152.4**		**47**	**32.6**
SEM	**8.29**	**8.20**	**7.79**	**6.96**		**3.63**	**5.22**

Table 2 shows the kinematic biomechanical indicators specific to back giant with turn twist 360° in handstand, performed by 5 gymnasts - finalists on this apparatus.

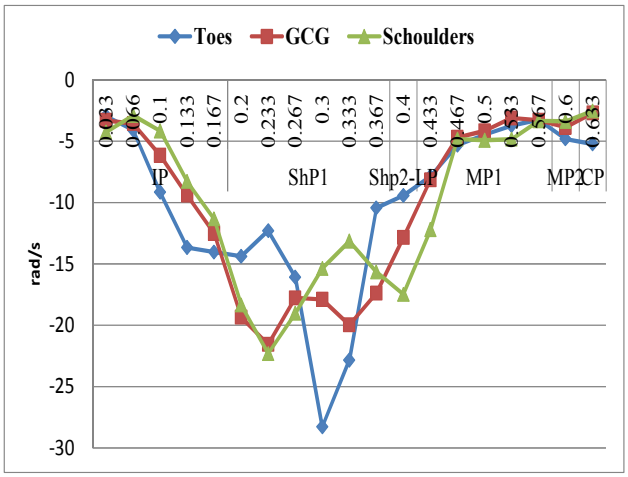


Fig.5. Biomechanical characteristics of back giant with turn twist (360°) in handstand, gymnast SS

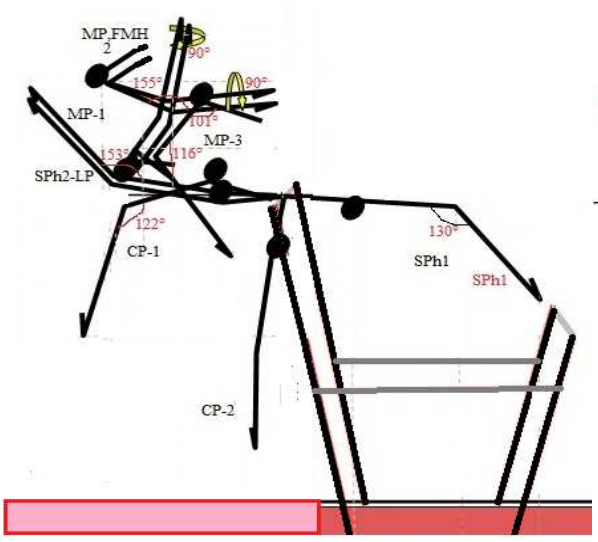


Fig.6. Gienger – Salto (T.P)

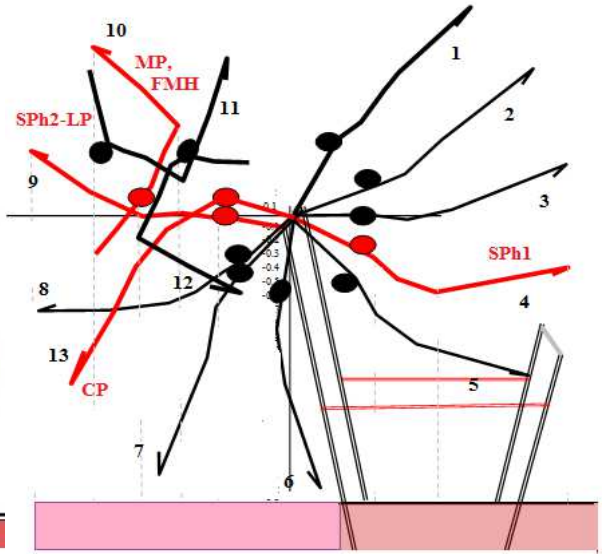


Fig.7. Jaegar – Salto (O.A-M)

Figure 5 shows the results of the angular velocity of body segments (Toes, GCG and Shoulders joint) of the gymnast SȘ., regarding the key elements of sports technique while performing the back giant with turn twist (360°) in handstand.

Figure no. 6 shows the key elements of sports technique of stretched Gienger salto on uneven bars executed by the athlete named T.P.; there are 25 frames, each one representing a certain phase of movement phasic structure, namely: PM – preparatory movement, formed of 14 frames, frame 7 – SPh1, frame 14 – SPh2 – LP (launching posture – release of the bar), frame 18 maximum height of GCG flight (MP), frames 16 and 20 the second phase of backward stretch salto with S turn (180°) and frame 22 – CP (concluding posture of re-grip to hang on bar).

Figure no. 7 shows the key elements of sports technique of Jaeger salto on uneven bars executed by the athlete named O.A-M.; there are 13 frames, each one representing a certain phase of movement phasic structure, namely: PM – preparatory movement, formed of 9 frames, frame 4 – SPh1, frame 9 – SPh2 – LP (launching posture – release of the bar), frame 10 maximum height of GCG flight (MP), frames 11 and 12 the second phase of salto and frame 13 – CP (concluding posture of re-grip to hang on bar).

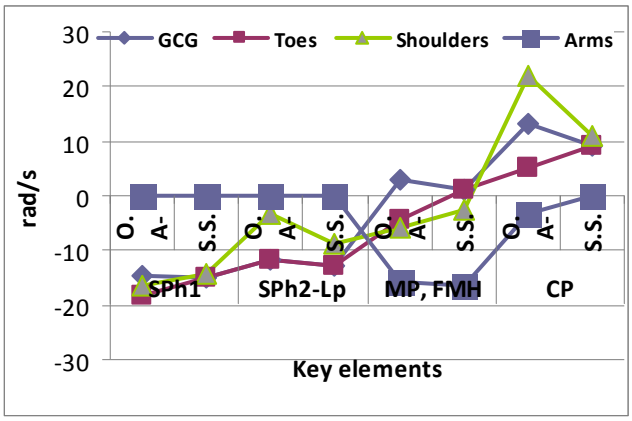


Fig. 8. Results of angular velocity of 12-14 years junior gymnasts' body segments during the execution of Jaeger salto on uneven bars (O.A-M)

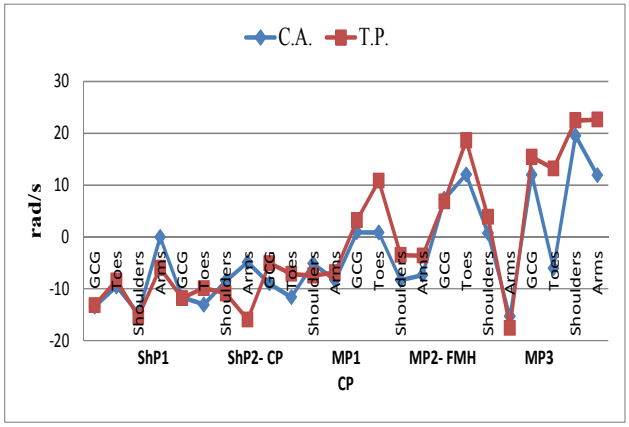


Fig. 9. Results of angular velocity of 12-14 years junior gymnasts' body segments during the execution of stretched Gienger salto on uneven bars (C.A. and T.P.)

Figure 8 shows the results of angular velocity of 12-14 years junior gymnasts' body segments during the execution of Jaeger salto on uneven bars, executed by the gymnast O.A-M; figure 9 shows the results of angular velocity of 12-14 years junior gymnasts' body segments during the execution of stretched Gienger salto on uneven bars, executed by the gymnasts C.A. and T.P.

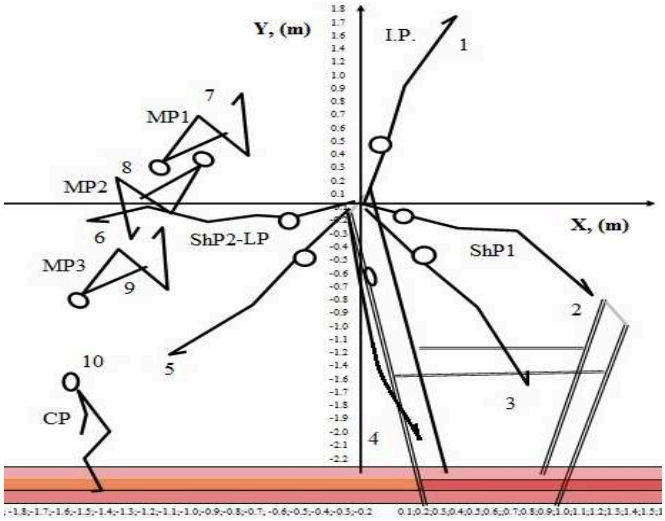


Fig.10. Dismount with backward tucked double salto (B.A.)

Note: IP- initial position, SPh1 – sub-phase 1 – passing over low bar; SPh2 – L.P. – sub-phase 2 – body launching posture (release of bar); BP – basic phase, MP1 – 3- multiplication of body posture, FMH - flight maximum height; FP – final phase, CP – concluding body posture (landing)- CP.

Figure 10 shows the the key elements of sports technique of dismount with backward tucked double salto, executed by gymnast B.A.

Figure 11 highlights the kinematic characteristics of the angular velocity of body segments during the dismount off the uneven bars with backward tucked double salto, executed by gymnast B.A.

Figure 12 shows the dynamic characteristics of force momentum of body segments during dismount off uneven bars with backward tucked double salto, executed by the gymnast B.A.

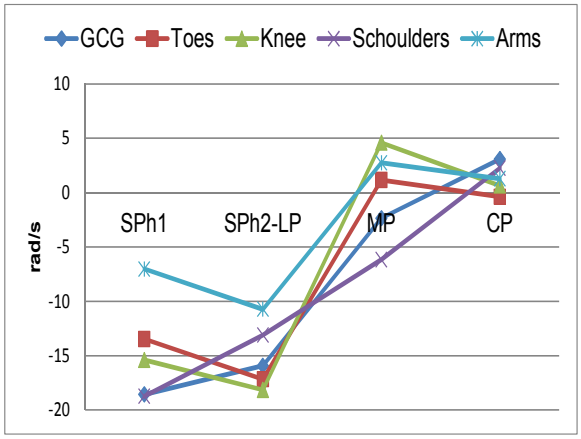


Fig.11. Kinematic characteristics of angular velocity of body segments during dismount off uneven bars with backward tucked double salto (B.A.)

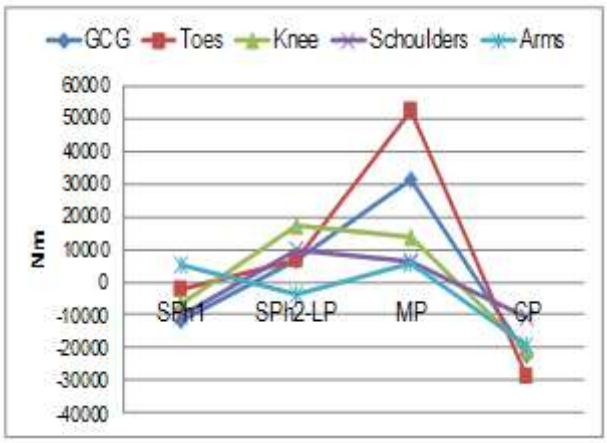


Fig. 12. Dynamic characteristics of force momentum during dismount off uneven bars with backward tucked double salto (B.A.)

Table 3. Results of the scores achieved in competition by the junior gymnasts 12 to 15 years old for the uneven bars in the Master National Championships of Artistic Gymnastics (n = 7)

	Athlete	All-around			Apparatus finals	
		Score D	Score E	Final score	Result	Rank.
1.	B.A.	4.500	8.500	13.000	12.725	4
2.	P.A.	3.600	8.575	12.175	11.075	8
3.	I.A.	5.300	8.900	14.200	13.125	2
4.	O.A-M.	5.100	8.550	13.650	12.600	5
5.	T.D.	4.800	7.425	12.225	12.125	6
6.	T.P.	5.100	8.525	13.625	13.100	3
7.	S.S.	5.000	8.450	13.450	13.500	1
	Statis.Ind.					
	Mean	4.77	8.42	13.19	12.61	
	SEM	0.22	0.17	0.29	0.30	
	SD	0.58	0.46	0.76	0.81	

Note: score D (difficulty), score E (execution), rank.- ranking

In table 3 are shown the performances achieved by the junior gymnasts aged 12 to 15 at the Masters National Championships of Artistic Gymnastics, carried out during the period 16-18.XI.2012, in terms of difficulty, execution and final score in the individual competition and the finals on apparatus.

Discussions

The analysis of the groups of elements as per the Code of Points (FIG, 2013, p.70-103) and the results of the research enable us to point out the following characteristics of the transfer or rotational movements on uneven bars:

1. Casts and Clear hip circles – 2.101 – 2.107, the element analyzed was - Clear hip circle to handstand (hstd), also with hop-grip change in hstd phase, or with ½ turn (180°) to hstd, code 2.305, value C (0.3 point); the vertical transfer will be achieved by the execution of the element - Clear hip circle with 1/1 turn (360°) to hstd, 2.405 – value D (0.4 point) and Clear hip circle with 1½ turn (540°) to hstd, code 2.505 – value E (0.5 point).

2. Giant circles – 3.101 - 3.110, the analyzed elements have been the following ones:

- *Giant circle bwd with 1/1 turn (360°) to hstd*, code 3.301 – value C (0.3 point), made by vertical transfer from Giant circle bwd in regular grip, or on one arm: also with ½ turn (180°) to hstd, code 3.201 – value B (0.2 point) which can increase its difficulty and become Giant circle bwd with 1½ or 2/1 turn (540° or 720°) to hstd, also with hop 1/1 turn (360°) to hstd, code 3.401 – value D (0.4 point);

- *Swing fwd and salto bwd with ½ turn (180°) piked or stretch (Gienger Salto) – to hang on HB* or Swing fwd with ½ turn (180°) and salto fwd straddled (Deltchev Salto), code 3.405 – value D (0.4 point), vertical transfer will be made by executing - Swing fwd and salto bwd stretched with 1½ turn (540°) to hang on HB, code 3.705 – value – G (0.4 point);

- *Jaeger Salto straddled or piked to hang on HB, cod 3.408 – D (0.4 point) performed by transfer of movement* - Swing bwd salto fwd tucked to hang on HB (Jaeger-Salto), code 3.308, value – C (0.3 point) and the increase of difficulty is achieved by - Jaeger Salto stretched to hang on HB Jaeger Salto straddled with ½ turn (180°) to hang on HB, code 3.508, value – E (0.5 point) and Swing bwd with salto fwd tucked over HB to hang on HB, code 3.708, value – G (0.7 point).

3. Dismounts – 6.101 – 6.110, the analyzed elements have been the following ones:

- Swing fwd to double salto bwd tucked, code 6.205, value – B (0.2 point), the increase of difficulty by vertical transfer was made by - - Swing fwd to double salto bwd piked, code 6.305, value – C (0.3 point), Swing fwd to double salto bwd tucked or piked with 1/1 turn (360°) in first or second salto, code 6.405, value – D (0.4 point), Swing fwd to double salto bwd tucked with 1½ turn (540°), code 6.505, value – E (0.5 point) and Swing fwd to double salto bwd tucked with 2/1 turn (720°), code 6.605, value – F (0.6 point).

- *Swing fwd to salto bwd stretched with 1½ turn (540°) or 2/1 turn (720°), code* 6.304, value – C (0.4 point) the increase of difficulty by vertical transfer was made by Swing fwd to salto bwd stretched with 2½ turn (900°), code 6.404, value – D (0.4 point) and Swing fwd to salto bwd stretched with 3/1 turn (1080°), code 6.504, value – E (0.5 point).

The biomechanical characteristics of rotational movements transfer on uneven bars show the anthropometrical and biomechanical indicators specific to each type of movement, the kinematic and dynamic aspects of the key elements of sports technique in accordance with the rotation of body segments around a fixed axis, free flight (dismounts) and mixed (releases). The changes in the basic phase of multiplication of body posture, by uniaxial or biaxial rotation of the body highlight the difficulty and how the transfer is made.

Conclusions

The biomechanical indicators required by the video computerized analysis used in this research show the number of studied cases, gymnasts' weight and size in handstand position; there are also shown the characteristics of the rotational movement around a fixed point on the apparatus in terms of rotational inertia and radius of movement of the analyzed body segments.

The use of the postural orientation method based on the biomechanical analysis of the routines on uneven bars highlighted the kinematic and dynamic characteristics of the key elements of sports technique, the modality and directions of transfer achievement in conformity with the performances obtained in competition.

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