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Improving Sports Technique of Jaeger Salto on Uneven Bars Based on Biomechanical Indicators

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Abstract

This paper aims at improvement of key sports technique elements using kinematic and dynamic indicators of Jaeger salto on uneven bars during the training stages. The methods used in this research include analysis of the literature; evaluation of techniques of gymnastics exercises using algorithmic structural–systemic analysis of movement; video-computerised methods using 'Pinnacle Studio', 'Kinovea' and 'Physics ToolKit'; movement postural orientation and evaluation of sports technique with complex coordination of movement structure; linear-branched programming of learning and improvement; and the 'KyPlot' program. Correlative analysis of the indicators of Jaeger salto and performances by 12–15-year-old gymnasts highlighted the connection between the kinematic and dynamic characteristics of sports techniques and the scores in competitions. Video-computerised methods, the method of movement postural orientation and algorithmic analysis of sports technique of Jaeger salto on uneven bars contributed to effective development of long-term learning programmes, improvement of technical execution and achievement of better performances.

Keywords: Gymnastics, uneven bars, biomechanics, key elements, long-term programmes of learning, performance.

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1. Introduction

Currently, artistic gymnastics has recorded important progresses, proving that it develops in accordance with the trends in performance sport, though it also has its specific features [1]. At the same time, it highlights a new level of development due to changes in the Code of Points, in terms of content and structure of the exercise and composition requirements [2].

Thus, the technique is represented by a system of specific motor structures rationally and economically built, in order to obtain the maximum efficiency in competition. The analysis of technique highlights the following components: technical element, technical procedure, style and basic mechanism [3]. The effective learning, in different stages of technical training, can be provided only if the learning stages and their content are closely related to the efficiency criteria [4]. Analysing the technique of gymnastics exercises, in terms of bio-mechanical positions, the 'arithmetical' entry is used, involving operations of improvement of concrete matters [5].

According to the requirements and the specific character of the Women's Artistic Gymnastics apparatus, the elements on uneven bars are split into several structural groups defined not only by the way of execution but also by their purpose, namely: straightening, clear hip circles, free passes over bars, hops and grips, simple turns in the longitudinal axis or turns with different BMs, passes from one bar to another, mounts and dismounts [6–9]; straddled or legs together pike Jaeger salto is a part of the third group of skills – giant circles, with difficulty value D – 0.4 and E – 0.5 points [2].

In the specialised literature, the general problems of biomechanical analysis of contemporary technique and the knowledge of factors decisive for the technical training and content of gymnastics training improvement are insufficiently treated and known. Current concerns in scientific research on the biomechanical issues in gymnastics and the characteristics of rotation routines were expressed by Hochmuth, Marthold, 1987; Bruggmann, 1994; Witten, Brown, Espinoza, 1996; Prassas, Papadopulous, Krug 1998 [10, 16].

The review of the specialised literature certifies the importance of research on sports techniques in gymnastics exercises and their learning, taking into account the body postures and positions. In connection with this, Boloban and Biriuk (1979) propose the use of movement postural orientation method for the research of gymnastics sports technique. In recent years, the conception and methodology necessary for using this method have been refined [17, 19].

The *purpose of the paper* is to highlight the dynamics of the kinematic and dynamic indicators of Jaeger salto on uneven bars made by 12–15-year-old gymnasts in the basic specialisation stage of training.

Hypothesis of the paper. We consider that the biomechanical analysis of Jaeger salto on uneven bars, based on the achievement of the macro methods of learning in the case of young gymnasts aged 12–15 years, will contribute to the development of sports technique key elements and to the improvement of the dynamic and kinematic characteristics of movement.

2. Methodology

The research was conducted during 2012–2014, monitoring the performances of the gymnasts in three national events on uneven bars. The subjects were four athletes 12–15 years old; all of them were components of the junior national team of Romania.

The methodological character of this research consists of generalisation and systematisation of the large number of scientific data and practical experience related to knowledge formation. Thus, the macro methods for learning the gymnastics exercises are presented as a modern dynamic system that includes and integrates the technological, didactical, biomechanical and motor structures of the exercises to be learnt. The objective practical–scientific argumentation for elaborating the macro methods to learn gymnastic exercises with increased difficulty was possible thanks to the use of modern theories [19].

Research methods used: The method of theoretical and methodological analysis of the literature related to artistic gymnastics; method of evaluation of gymnastics exercises sports technique using the movement algorithmic analysis [20]; video computerised method by means of: 'Pinnacle Studio', 'Kinovea' and 'Physics ToolKit' programs; method of movement postural orientation and evaluation of key elements of sports technique with complex coordination of movement structure [18]; method of linear-branched programming of gymnastics exercises learning and improving [19]; and statistical method by means of 'KyPlot' program.

The biomechanical analysis was made by means of the Physics ToolKit Version 6.0 program, monitoring the key elements of sport technique of Jaeger straddled and piked salto, divided into two parts: *rotation motion with rotation axis on apparatus,* in terms of preparatory movement (PM) phase: Sub-phase 1 (SPh1) spring under bar; Sub-phase 2 (SPh2-LP) body launching posture – moment of release of the bar; *translation and rotation motion* with GCG rotation axis regarding the basic movement (BM) phase – multiplication of body position (MP) – salto forward straddled or stretched to hang on HB and the concluding movement phase (CM) – concluding posture (CP) of bar re-grasping (Figure 1).

Figure 1. Key elements of sport technique of Jaeger salto. (a) Straddled to hang on high bar. (b) Piked to hang on high bar

3. Results

Table 1 shows the anthropometric and biomechanical indicators required for the biomechanical analysis of stretched or piked Jaeger salto executed on the high bar of uneven bars, in terms of weight and height with arms up, for calculation of the inertia of rotation (IR), and the radius of body segments movement (toes, GCG, shoulders joint, arms) during the phase of rotation with and without support.

Table 1. Anthropometric and biomechanical indicators required by the biomechanical analysis of sports technique used in Jaeger salto stretched on uneven bars ($\bar{x}$ ± SD)

Test	Jeager salto	*N*	Rotation movement with support						Rotation movement without support			
			Weight (kg)	HwAU (m)	IR (kg·m^2)	Toes (m)	CGG (m)	S.J. (m)	IR (kg·m^2)	Toes (m)	S.J. (m)	Arms (m)
2012–2013	Strad.	5	37.6	1.91	137.78	1.702	0.982	0.545	17.33	0.722	0.453	0.873
			3.25	0.01	12.45	0.07	0.03	0.01	1.52	0.09	0.06	0.108
	Piked	2	33.0	1.82	108.11	1.586	0.944	0.482	13.66	0.612	0.387	0.752
			0.00	0.00	0.00	0.01	0.04	0.04	0.00	0.01	0.02	0.01
2014	Strad.	8	39.98	1.93	145.89	1.75	1.035	0.553	18.64	0.69	0.456	0.856
			1.48	0.04	16.24	0.15	0.07	0.044	2.29	0.11	0.04	0.11
	Piked	4	38.6	1.90	132.91	1.764	1.033	0.534	16.79	0.708	0.465	0.889
			0.00	0.03	12.55	0.15	0.07	0.07	1.58	0.17	0.04	0.08

Note: HwAU – height arms up; IR – inertia of rotation in phase of rotation movement without support = ½ m · ½ r^2 (½ body weight × ½ body height arms up^2)

In Table 2, the comparative results of the biomechanical analysis indicators are listed, which characterise the kinematic structure of the key elements of sports technique used in Jaeger salto straddled or piked according to joint angles data (by means of 'Kinovea' program), executed in competition conditions during the Romanian National Championships of Artistic Gymnastics, Bucharest 2014 and the Romanian National Championships of Artistic Gymnastics, Onești 2012.

Table 2. Comparative indicators of angular characteristics of body segments during execution of sports technique key elements of Jaeger salto on uneven bars

Testing	Jeager Salto	*N*	Statist. Indicat.	Phase of preparatory movement				Phase of basic movement	Concluding phase	
				P.I. (degree)	SPh 1 (degree)	SPh 2 (degree) *a*	*b*	MP (degree)	CP (degree) *a*	*b*
Initial 20122013	Straddled	5	Mean	4.6	123.6	192.2	213.8	108.0	132.8	146.4
			SD	2.30	8.79	6.06	10.94	8.18	15.16	27.26
	Piked	2	Mean	3.5	139.5	187.5	209.5	106.0	129.5	138.5
			SD	0.71	0.71	3.54	0.71	14.14	16.26	17.68
Final 2014	Straddled	8	Mean	5.75	127.13	184.88	205.5	72.88	148.88	168.88
			SD	2.49	11.32	8.43	19.27	23.95	19.39	27.21
	Piked	4	Mean	5.5	127.75	182.75	215.5	89.5	148.5	135.5
			SD	2.65	8.77	13.05	10.66	9.29	6.56	13.60

Note: SPh1 – sub-phase 1 – passing over low bar; SPh2 – L.P. – sub-phase 2 – body launching posture (release of bar); MP – FMH – multiplication of body posture – flight maximum height; CP – concluding posture of re-grasping the bar; TI –initial testing, TF – final testing

Figure 2 shows the individual spatial–temporal characteristics of gymnast O.A-M (15 years old), in terms of GCG trajectory during straddled Jaeger salto execution on high bar of uneven bars in competitive conditions in the National Championships of Romania during the period 2012–2014.

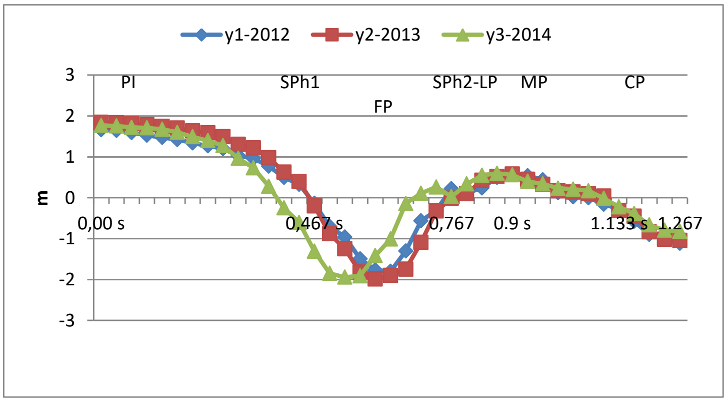

Figure 2. Graphical representation of GCG trajectory during Jaeger straddled salto execution on high bar of uneven bars, gymnast O.A-M (15 years old)

Figure 3 graphically presents the individual values of the angular speed of body segments during Jaeger straddled Jaeger salto execution on high bar of uneven bars by the athlete O.A-M. (15 years old), concerning the phase of PM for rotation with support and the basic phase of rotation without support and conclusion.

Table 3 presents the correlation between the biomechanical indicators of the key elements of sports technique of straddled and piked Jaeger salto and the results achieved in the National Championships of Romania, Bucharest 2014.

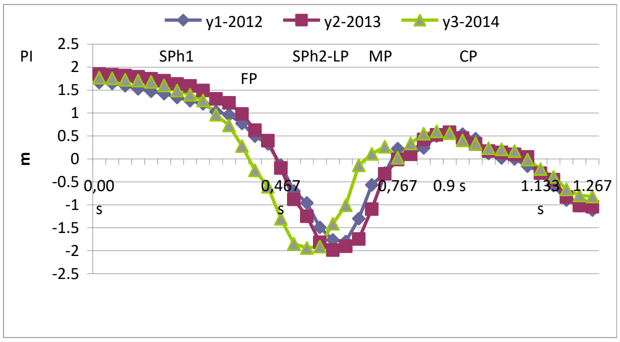

Figure 3. Graphic representation of angular speed of body segments during execution of Jaeger straddled salto execution on high bar of uneven bars, gymnast O.A-M (15 years old). (a) Phase of PM of rotation with support. (b) Phase of BM of rotation without support and conclusion

Table 3. Results of correlative analysis of biomechanical indicators of stretched Jaeger salto on uneven bars and results of competitions held in 2014 (*n* = 9)

No.	Indicators*		Indicators															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	IR (kg·m^2)	with S	-	0.152	0.202	0.019	0.131	0.368	0.168	−0.502	*0.719*	−0.194	−0.249	0.490	0.185	*−0.962*	0.341	0.077
		w/o S	*0.993*	0.239	*0.190*	*0.034*	0.109	0.328	0.121	−0.546	*0.693*	−0.219	−0.355	0.476	0.193	*−0.960*	0.402	0.142
2	RM with support (m)	toes	-	-	*0.981*	*0.709*	*0.884*	*0.874*	*0.891*	0.244	0.338	−0.475	0.132	0.393	0.636	−0.141	−0.134	−0.182
3		GCG	-	-	-	*0.707*	*0.852*	*0.893*	*0.874*	0.240	0.353	−0.456	0.110	0.347	*0.689*	−0.199	−0.085	−0.148
4		shoulder	-	-	-	-	0.614	0.402	0.411	0.038	0.054	−0.263	−0.158	0.016	0.502	0.028	0.273	0.295
5	RM w/o support (m)	toes	-	-	-	-	-	*0.758*	*0.856*	0.168	0.546	*−0.329*	0.167	0.135	0.465	−0.182	−0.048	−0.103
6		shoulder	-	-	-	-	-	-	*0.911*	0.125	0.483	*−0.297*	0.299	0.525	0.547	−0.376	−0.221	−0.343
7		arms	-	-	-	-	-	-	-	0.340	0.449	*−0.439*	0.455	0.431	0.468	−0.164	−0.324	−0.389
8	KE (degrees)	SPh1	-	-	-	-	-	-	-	-	−0.412	−0.235	0.483	−0.187	0.366	0.538	−0.723	−0.603
9		SPh2.1	-	-	-	-	-	-	-	-	-	−0.192	0.028	0.309	0.041	*−0.768*	*0.318*	0.110
10		SPh2.2	-	-	-	-	-	-	-	-	-	-	0.139	−0.508	−0.401	0.041	−0.119	−0.113
11		MP	-	-	-	-	-	-	-	-	-	-	-	0.138	−0.194	0.283	−0.623	−0.572

12		CPa	-	-	-	-	-	-	-	-	-	-	-	-	0.145	−0.356	−0.113	−0.223
13		CPb	-	-	-	-	-	-	-	-	-	-	-	-	-	−0.178	−0.192	−0.255
14	AA, AF (points)	difficult	-	-	-	-	-	-	-	-	-	-	-	-	-	-	−0.313	*−0.037*
15		execut.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*0.961*
16		score	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Note: Tables 1 and 2; *r*- Pearson's correlation coefficient, $p < 0.05$, $r = 0.683$; $p < 0.01$, $r = 0.833$; IR – inertia of rotation, RM – radius of movement of body segments; SPh2.1 – thigh-torso angle; SPh2.2 –torso-arms angle; CPa- thigh-torso angle; CPb - torso-arms angle; KE – key elements, AA – all-around, AF - apparatus finals

4. Discussion

The method of video-computerised analysis of Jaeger salto, in accordance with the method of movement postural orientation, enabled highlighting and identification of the key elements whose learning deepens the understanding of the sports technique of gymnastics exercises and allows the development of modern programmes for their learning.

The macro methods of learning difficult acrobatic and gymnastics exercises of coordination and the logical–structural diagram for achievement in sports training are well presented by Prof. V. Boloban (1988). Structurally, the macro methods introduce the functional assembly of long-term programmes for learning the exercises of 'movement school', the basic level of specialisation of the arbitrary and final programmes and the development of physical qualities consistent with the technical training based on the influence of key concrete goals of gymnasts' sports training [18, 19].

Comparative analysis of the results of the anthropometric and kinematic indicators necessary for the biomechanical analysis of straddled Jaeger salto (Table 1) reveals the increase in body weight and height with arms up during final testing (straddled salto – by 2.38 kg and 0.02 m, and pike salto by 5.6 kg and 0.08 m), which influence the change in the value of IR (kg•m^2) both in the phase of rotation with support and in the phase of rotation without support. Regarding the radius of body segments movement during the phase of rotation with support in the PM, we observe the decrease in toes radius of movement (RM), which led to improvement in the execution of SPh1 and SPh2-LP. It also improved the flight phase of straddled and pike salto by reducing the RM of toes in straddled salto and increasing it – pike salto, increasing the RM of shoulders and arms in pike salto and reducing the RM of arms in straddled salto. All these changes of RM entailed the improvement of the CP – re-grasping of bar.

Analysis of the indicators of the kinematic structure of sports technique key elements in Jaeger salto on uneven bars according to the joints data made it possible to highlight the mean of joints' angles and the significance of the differences between tests [Table 2, Figure 1(a)]:

i) Straddled salto:

a) During the PM phase, in the launching posture (LP) – handstand, the mean of the angle between toes and the vertical is 4.6° in initial testing with an increase by 1.15° in final testing. In SPh1, which presents the moment before passing over the low bar, the mean of the angle between hip and torso has a value of 123.6° in initial testing with an increase by 3.53° in final testing. The SPh2-LP, posture of releasing the high bar, is characterised by the diminution of the hip–torso angle by 7.32° and torso-arms by 8.3° in final testing, which contributed to improvement of the PM for the salto.

b) During the BM phase, multiplication of body posture (MP) at the moment of GCG maximum height, there is a diminution of the hip–torso angle by 35.2° in final testing, which allowed to improve the flight phase of the salto.

c) The concluding phase, re-grasping of bar in hung position highlights the increase in angle between hip and torso in final testing, removing the legs from the bar (by 16.08°) and the angle torso-arms by 22.48°, which contributed to the improvement of phase and an easy re-grasping of the bar with stretched arms.

ii) Piked salto [Table 2, Figure 1(b)]:

a) in PM phase, at LP – handstand, a mean of the angle between toes and the vertical of 4.6° in initial testing with an increase by 2.0° in final testing. In SPh1, which is the moment before passing over the low bar, the mean of the hip–torso angle has a value of 139.5° in initial testing and a decrease by 11.75° in final testing. The SPh2-LP, the posture of releasing the high bar, is characterised by diminution of the angle between hip and torso by 4.75° with increase in torso-arms angle by 6,0° in final testing, which led to improvement of the PM for beginning the salto.

b) in BM phase, multiplication of body posture (MP) at the moment of GCG maximum height, there is a decrease in the angle between hip and torso by 16.5° in final testing, which made it possible to improve the flight phase of the salto.

c) in the concluding posture, re-grasping of the bar in hung position, we notice increase of the hip–torso, removing the legs from the bar by 19.0° and decrease of the torso-arms angle by 3.0°, which improved the re-grasping of the bar with stretched arms.

Comparative analysis of the spatial–temporal individual characteristics of GCG trajectory in the straddled Jaeger salto (Figure 2), executed by gymnast O.A-M (15 years old), reveals the temporal synchronisation of the PM in SPh1 (0.433 sec in both the tests) and a slight desynchronisation in SPh2-LP (0.767 sec in initial testing and 0.733 sec in final testing), increase of maximum height of GCG in the basic phase of movement in MP (0.578 and 0.579 m in initial testing and 0.599 m in final testing) and GCG removing from the bar and lifting it closer to the horizontal of the high bar, which highlights the improvement of the CP in the concluding posture of the movement – re- grasping of the bar in hung position.

Comparative analysis of the individual kinematic characteristics of the angular speed of straddled Jaeger salto [Figures 3(a) and (b)] executed by gymnast O.A-M, aged 15 years, points out higher values in the PM at the toe level of 13.046 rad/sec; 9.556 and 8.591 for GCG and shoulders; in SPh1 – higher values at toe level; in SPh2-Lp the value of angular speed has an increase at shoulders (12.769 rad/sec) and arms (6.467 rad/sec) with a slight breaking at the heels (4.926 rad/sec) – with the effect of blocking and preparing the salto beginning; in the BM phase, in MP maximum height of GCG , the value of angular speed is higher at arm level (18.754 rad/sec) and shoulder level (10.356 rad/sec), which contributes to achievement of the salto (rotation around the hip axis). There is also a smaller value at the heel, namely 6.028 rad/sec, which leads to the movement rotation; in movement concluding posture CP – re-grasping of the bar – the higher values are at the heels (10.477 rad/sec), which contributes to the completion of salto rotation, then at the arms (–4.069 rad/sec) for re-grasping the bar – and at shoulders 0.407 rad/sec – for fixation.

The results of the correlative analysis (Table 3) highlight the following: strong connections between the indicators at $p < 0.01$ IR in the phase of rotation with support and IR in the phase of rotation without support and the difficulty score; RM of toes and GCG with support and RM of toes, shoulders and arms without support; RM of toes and shoulders without support and RM of arms without support; strong connections at $p < 0.05$ IR with and without support and angle between hip and torso in SPh2.1; RM of toes with support and RM of shoulders with support; RM of GCG with support and RM of shoulders with support and the angle between torso and arms in CPb; RM of toes without support and RM of shoulders without support; the hip–torso angle in SPh1 and the execution score;

the hip–torso angle in SPh2.1 and the difficulty score. The connections with the other indicators of the biomechanical characteristics and the performances achieved in competition are moderate, poor or even inexistent.

5. Conclusion

The results of the spatial–temporal characteristics of sports technique key elements of Jaeger salto on uneven bars highlight the phasic sequence of execution, namely the PM of launching from forward giant, moment of bar release, multiplication of body posture and the concluding posture of re-grasping the bar, in accordance with technical requirements of the FIG Code of Points.

The correlative analysis between the biomechanical indicators of Jaeger salto and the performances achieved in competition on uneven bars by gymnasts aged 12–15 years reveal strong and moderate connections between the kinematic characteristics of sports technique key elements and the scores obtained in competition. As for the weak connections, they require special attention for improving the phasic structure of body posture.

The analytical video biomechanical processing of each segment has led to centralisation of the spatial–temporal indicators of the key characteristics of Jaeger salto on uneven bars, according to the data on joints movement trajectories and the graphical representation of the entire body segments of junior gymnasts aged 12–15 years.

The use of a video-computerised method in accordance with the method of movement postural orientation and algorithmic analysis of sports technique of Jaeger salto on uneven bars contributed to the more effective development of long-term learning programme content, the improvement of technical execution and the achievement of better performances in competition, which confirms the hypothesis proposed in this paper.

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