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THE KINEMATIC MODEL OF THE BOUNCE–OFF PHASE IN SOME ACROBATIC ELEMENTS WITH FORWARD BODY ROTATION

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Abstract. *The aim of this study was a comparison of the kinematic parameters important for defining a model technique of the push-off phase in performing acrobatic elements with forward body rotation, as well as the first hand support, the bounce-off and the flight phase, as key phases in performing acrobatic elements with hand support and forward body rotation. The comparison of kinematic parameters was made based on recorded tapes of forward handsprings and handspring saltos forward tucked to roll out, performed by top class gymnasts. It was made on the individual execution phases of the same elements related to the hand support phase, bounce-off hands phase and flight phase. The data was processed with the Ariel Performance Analysis System (APAS, 1995). The values indicating the significance of the handspring salto forward tucked to roll out as an exercise in training methods of the bounce-off hands phase were obtained by analyzing the kinematic parameters essential in defining a correct technique of the bounce–off hands phase, in executing acrobatic elements with forward body rotation and hand support. The correct execution of the bounce–off hands phase makes the achievement of proper flight altitude possible, which is essential for learning more complex acrobatic elements with a high degree of difficulty, whose performance includes multiple rotations around the transversal and/or longitudinal axis.*

Key words: *push-off phase, kinematic parameters, handspring salto forward tucked to roll out*

1. INTRODUCTION

Sport gymnastics is classified in the group of conventional sports, considering that the aesthetic component and acyclic movement values are based on strict rules of the Code of Points (FIG, 2006). Because of the structural complexity of movements in sport gymnastics, great attention is given to the execution of the basic acrobatics that later evolves into

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more complex and more difficult elements. Due to this, training must be directed towards the achievement of a model execution, toward maintaining and improving it over a long period of time (Sands, W.M.A. et al., 1999). The importance of acrobatics in sport gymnastics is evident in the quantity of the elements performed in gymnastics compositions, especially in women's sport gymnastics, in vault, balance beam and floor exercises. Acrobatic elements are important in the procedure of teaching gymnastics elements on other apparatuses (Karascony and Čuk, 2005).

The demanding nature of ever more complex gymnastics elements is constantly growing, making it difficult for experts to see and monitor them, and obstructing the correction of errors in the performance of certain movements and non – model executions. Biomechanical research provides us with concrete and quantitative information, on the basis of which relevant parameters for the successful performance of specific elements can be defined. The possibility of error detection based on quantified information is far more precise than the one based on visualization, which ensures a quicker way towards an optimal execution of specific gymnastics elements (Živčić et al., 1997, 1999).

Changes in the valorization of the degree of difficulty of the forward body rotation acrobatic elements (FIG, 2001) have led to their increased presence in compositions on the balance beam and the floor. Acrobatic elements from the group of forward handsprings combined with somersault elements play a key role in performing acrobatic series with forward body rotation of a great degree of difficulty. According to the Code of Points in men's sport gymnastics, the handspring salto forward tucked to roll out has a B – D degree of difficulty, which places it among elements with a high degree of difficulty, while one cannot find it on the list of registered elements in women's gymnastics. In addition, a direct connection between the forward handspring and handspring salto forward - tucked salto forward off in vaulting, represents the 3rd group of vaults in men's sport gymnastics, while in women's gymnastics it represents the 2nd group of vaults. In men's sport gymnastics, its maximum value is 8.40 points (FIG, 2006), while in women's sport gymnastics it is 9.20 points.

The handspring salto forward tucked to roll out is used as a methodical exercise in training the forward handspring push-off phase, and is performed on the ground or higher ground. Great strength is required in the hands and shoulders for its execution, which is the reason why it is not represented in women's floor exercises. It is considered a basic element for learning more complex vaults with multiple rotations around the horizontal axis, as well as both horizontal and vertical axes, which are placed in a group of a high degree of difficulty with a maximum start value.

Due to the importance of learning the push-off phase when training similar technique elements with forward body rotation, this study is based on a kinematic analysis of the handspring salto forward to roll out as an acrobatic element from the forward handspring group of elements. Until today, biomechanical analyses have not provided a definition of kinematic parameters that would define the technique used for performing this element; therefore, this research has made a comparison of its parameters with those of similar elements, which have the same first three phases in their execution.

In research carried out to date, a kinematic analysis of the handspring salto to forward roll out as an acrobatic element in a floor exercise has not yet been made. Similar analyses have been made on similar acrobatic elements, such as the forward handspring on the floor and vault, as well as the handspring forward salto into a somersault on the vault (Forwood et al., 1985; Sands, 1994; Živčić et al., 1999; Živčić, 2000; Watanabe, 1997).

The goal of this research was a comparison of the kinematic parameters important for defining a model technique of the push-off phase in performing acrobatic elements with forward body rotation, as well as for the first hand support, bounce-off and flight phases, as key phases in performing acrobatic elements with hand support and forward body rotation.

2. Methods

The data for this study were obtained by recording with two VHS video cameras, with a frequency of 60 images per second. The data processing was carried out by the Ariel Performance Analysis System (APAS, 1995). With the help of the coordinates' digitalization of 18 points of reference, the 14-segment model of the human body was defined and the filtration of the coordinates was carried out with a Cubic Spline filter. Based on the data prepared in this manner, all of the relevant parameters related to the kinematics of the analyzed acrobatic elements of the technique were calculated. The figures demonstrating the performance technique of the forward handspring and handspring salto forward to roll out were created in a graphic module called APAS, while graphs were processed with a statistical program for data processing and presentation, called STATISTIC.

The comparison of the kinematic parameters was made based on tape recordings of the forward handspring and handspring salto forward tucked to roll out, performed by top class gymnasts. The comparison was made between individual execution phases of the same elements related to the hand support phase, the bounce-off hands phase and the flight phase.

The chosen kinematic variables were grouped into individual technique phases, describing relations between the length and height of the center of body mass (CM), the angles between certain body segments activated for performing both elements, the CM in relation to the surface, the horizontal and vertical CM velocities in characteristic performance positions, as well as the duration of each execution phase. The extracted parameters define a successful execution of the handspring salto forward tucked to roll out and forward handspring, and by analyzing them, it is possible to establish movement structure of the handspring salto forward tucked to roll out. Structural difference between the observed motor stereotypes, the importance of the bounce-off hands phase, as well as the correlation between certain kinematic variables in the hand support and bounce-off hands phases, are crucial for the correct execution of the flight phase.

3. Results

Table 1 shows that the length of the step into the handspring salto forward tucked to roll out (Figure 1) is 5.2 cm shorter and lasts 0.084 sec longer than in the performance of the forward handspring (Figure 2). The difference in the CM height is obvious immediately after the bound phase, where the CM is 8.8 cm lower than in the forward handspring. The distance between the hands and the take-off leg at the moment before the hand-support is 6.9 cm longer in the handspring salto forward to roll out, while the CM is 2.6 cm lower. Differences are also visible in the CM height in the bounce-off hands phase, which is 5 cm greater when performing the handspring salto forward tucked to roll out. Maximum flight phase altitude is 14.1 cm higher and the flight duration is 0.183 sec longer when performing the handspring salto forward to roll out. Great similarities are visible in the angles of the knees and hip joints in the first contact phase and the take-off phase. Differences in the knee joint are valued at 5° before and 3.7° at the take-off moment, while in the hip joint, they are 4.9° before and 5.6° at the take-off moment. Unlike the take-off leg, the differences in joint angles of the swing leg during the first foot-surface contact after the bound are great and vary between 9-21°. The angles between the CM and the surface are 2° higher in the first hand-surface contact and 2° lower in the bounce-off hands phase, when performing the forward handspring into a somersault with a minimal oscillation of the angle value in the shoulder joint at the hand-support contact moment (4.3°); however, the angle value is the same at the push-off moment. Significant differences were found in the shoulder joint angles at the maximum flight point, which is 88.5° lower in the handspring salto forward to roll out, 77.6° in the knee joints and by 115.2° in hip joints.

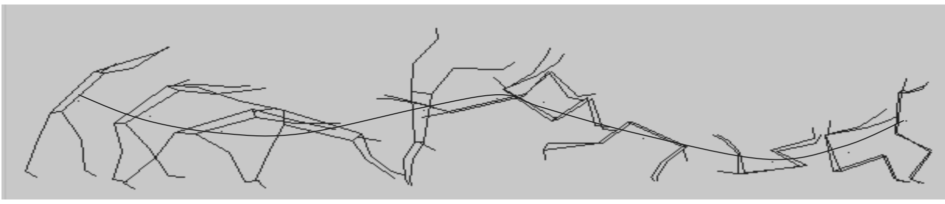

Fig. 1. Handspring salto forward tucked to roll out

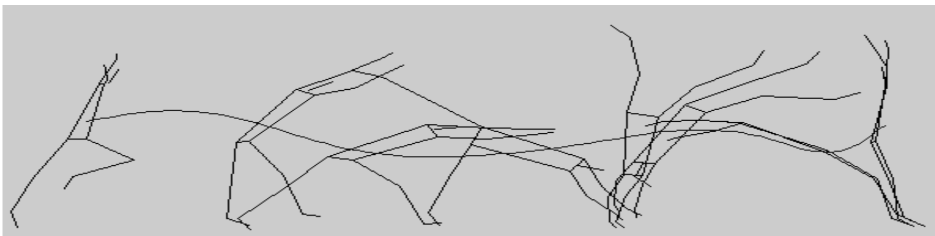

Fig. 2. Forward handspring

Table 1 presents the more significant differences in values of the CM vertical velocities at the moment of the lunge as well as after it, and at the first hand-surface contact, with noticeably higher values in the forward handspring somersault. These differences are reduce in the bounce-off hands phase, only to rise again in the flight phase, reaching a much higher value (141cm/sec), while in the forward handspring, the value of this component is 0 cm/sec.

It is obvious that the values of horizontal velocities, analyzed in key positions of the execution - the hand-surface contact, the bounce-off hands phase and the flight phase, are higher in the forward handspring somersault, considering the values of the horizontal and vertical CM velocities. The vertical CM velocity values are negative until the first hand-surface contact, after which they get much higher than in the forward handspring. In the bounce – off hands phase of the handspring salto forward tucked to roll out, the difference in values of the vertical CM velocity grew 273 cm/sec from the first hand-surface contact to the push-off moment, while in the forward handspring, it rose an insignificant 8 cm/sec.

Table 1. The kinematic parameters of the Forward handspring and Handspring salto forward tucked to roll out

Space and time parameters	F. Handspring		Handsp. Salto F.	
Lunge length (cm) *(DULJISK)*	96.100		90.900	
Lunge time (sec) *(VRTRISK)*	0.183		0.267	
CM height after bounding step (cm) *(CTYPKZN)*	90.700		81.900	
CM height in first contact take-off leg *(CTZPKON)*	68.400		65.300	
Hand-feet distance (cm) *(XRKODN)*	91.800		98.700	
CM height in first hand-surface contact (cm) *(CTYPKRU)*	71.900		69.300	
CM height in push-off phase (cm) *(CTYODRIV)*	90.200		95.200	
Push-off phase time (sec) *(VRTRRIV)*	0.233		0.200	
Max CM height in flight phase (cm) *(CTYMLET)*	93.200		107.300	
Flight phase length (cm) *(CTXLET)*	74.700		93.200	
Flight phase time (sec) *(VRTLET)*	0.300		0.483	
Angles (degrees)	F. Handspring		Handsp. Salto F.	
Knee A. in swing leg after bounding step *(AKPKZN)*	152		147	
Knee A. swing leg in last contact with surface *(AKZNZAM)*	174		155	
Knee A. swing leg during swing phase *(AKPKODN)*	182		184	
Knee A. take-off leg in take-off phase *(AKODRAZ)*	184		188	
Min knee A. take-off leg *(MINAKODR)*	144		141	
Hip A. take-off leg in first contact after bounding step *(AKUPKON)*	72		67	
Hip A. swing leg after bounding step *(AKUPKZN)*	151		130	
Hip A. swing leg during swing phase *(AKUZNZA)*	159		151	
Hip A. take-off leg at take-off moment *(AKUODRA)*	82		88	
Min hip A. in take-off phase *(MINAKUODRA)*	67		63	
Shoulder A. in first hand-surface contact *(ARPRVIK)*	137		141	
CM A. in first hand-surface contact *(ACTPRVIK)*	38		40	
CM A. in push-off phase *(ACTODRIV)*	102		100	
Shoulder A. in push-off phase (*ARODRIV)*	165		165	
Horizontal and vertical velocities (cm/sec)	F. Handspring		Handsp. Salto F.	
	X	Y	X	Y
CM velocity after bounding step *(VCTXPKZN - VCTYPKZN)*	289	–172	335	–95
CM velocity during swing phase *(VCTXZAM – VCTYZAM)*	314	–44	398	–109
CM velocity in first contact take-off leg *(CTXPKON – CTYPKON)*	314	–44	389	–128
CM velocity in take-off phase *(VCTXODRZ – VCTYODRZ)*	300	55	403	–221
CM velocity in first hand contact *(VCTXPKRU – VCTYPKRU)*	298	58	403	–181
CM velocity in push-off phase *(VCTXODR – VCTYODR)*	278	66	374	92
CM velocity in max flight phase *(VCTXLET – VCTYLET)*	268	0	356	141

CM – center of mass

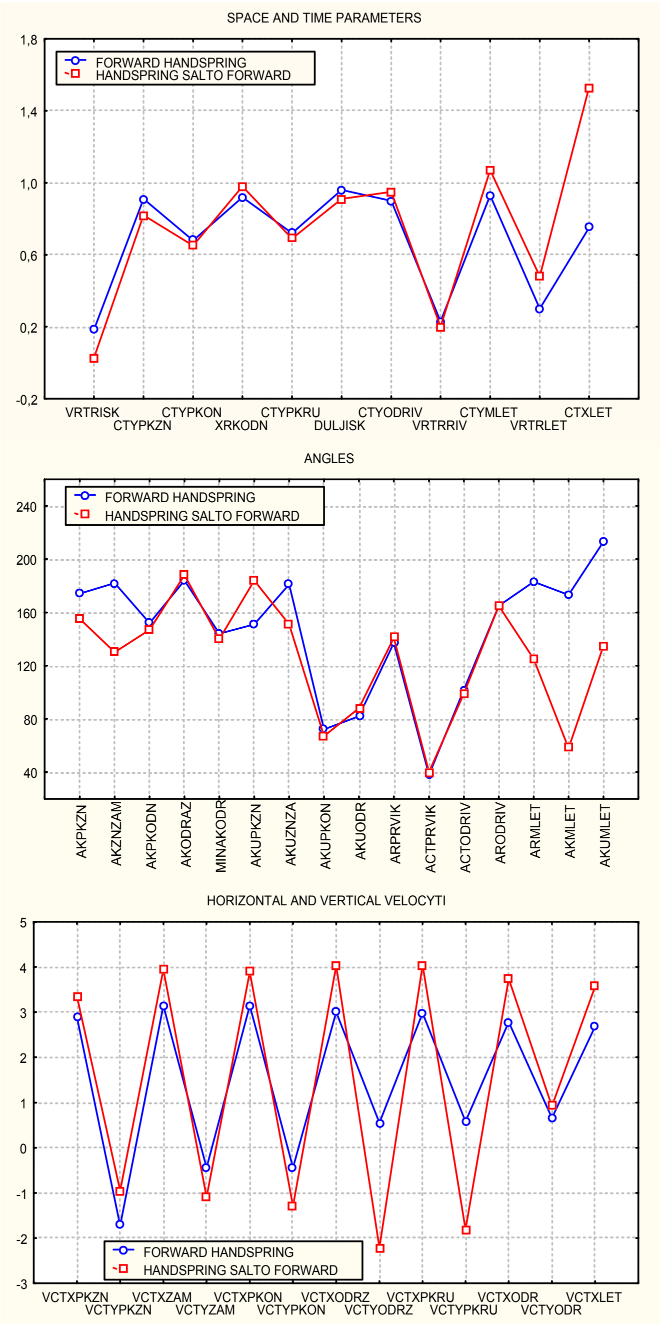

Fig. 3. The kinematic parameters of the Forward handspring and Handspring salto forward tucked to roll out

Analyzing the parameters of space and time in the forward handspring somersault and forward handspring, one can notice greater differences among most of the analyzed kinematic parameters (Figure 3). They are especially obvious during the lunge execution, which is crucial for the hand support phase. The obtained values show a sudden lowering of the CM in the performance of the handspring salto forward tucked to roll out from the first foot contact after the run and bound to the moment of the first hand support contact, which also caused a shorter lunge of the take-off leg than in the forward handspring. This created the preconditions for achieving a greater vertical CM velocity after the push-off moment in the bounce-off hands phase, which is crucial for the performance of the flight phase in the handspring salto forward to roll out (Figure 3). In order to perform the flight phase with body rotation completely on the transversal axis, starting with the push-off moment and ending with a new hand-surface contact, it is important to ensure an optimal vertical component of body movement, as well as to achieve an adequate flight altitude and length, which results in significantly different values in relation to the forward handspring flight phase.

Differences in angles (Figure 3) of the swing and take-off leg, as well as of the CM after the bound and at the moment of the first hand-surface contact, although small, point out that during this preparation phase, which is essential for the execution of the bounce-off hands phase and the flight phase, it was necessary to ensure the adequate conditions for the execution of the following phases in performing the handspring salto forward tucked to roll out, especially the flight phase. It is necessary to achieve an adequate vertical component of the handspring salto forward tucked to roll out in order to execute the flight phase, considering that this element of technique requires a higher and longer flight parabola. The differences in angle values among individual body segments during the flight phase (knee, hip and shoulder joints) clearly define the structural differences between these two movements. Angle reduction among all of the analyzed body segments in this phase, when performing the handspring salto forward to roll out, resulted in the reduction of the rotation radius, which made it possible for the body rotate a full 360° around the transversal axis.

By comparing the values of the CM movement velocities, it is obvious that the emphasis in the handspring salto forward to roll out is on the vertical component, as opposed to the forward handspring, which is primarily orientated on the horizontal CM movement.

4. Discussion and Conclusion

The kinematic analysis has provided the information that the handspring salto forward tucked to roll out is a highly complex acrobatic element and, due to this fact, rarely applicable in floor exercises. Its application is significant in methods for the bounce-off hands phase training for the forward body rotation acrobatic elements group, which include the hand support contact phase. It also has great significance for the learning process and the execution of the forward handspring vault group that includes performing a forward somersault, which includes a forward salto in its second execution phase in its basic form and with various multiple rotations around the transversal or around both the transversal and longitudinal axes of the body simultaneously. Due to the extremely demanding nature of the flight and landing phase execution, the handspring salto forward to roll out is used as a methodical exercise, initially performed from higher ground and then on ground level, after a gradual reduction in elevation. The basic preconditions for a successful performance of the handspring salto forward tucked to roll out are the mastered model technique of the forward handspring, as well as exceptional arm and shoulder muscle strength. For this reason, it is recommended for top class gymnasts as a methodical drill for training the bounce-off phase.

The reason for the application of this acrobatic element in the methodical procedures of training the forward body rotation technique elements with the hand support phase is visible in kinematic parameters that are prime for defining the bounce-off hands phase and that directly influence reaching a greater flight altitude, as well as flight duration.

The handspring salto forward to roll out is a technique element primarily orientated towards achieving a great flight altitude after the bounce–off hands phase, which indicates that earlier execution phases created adequate conditions for its successful realization. In the hand-surface contact moment phase, the horizontal movement component, achieved by the run, was compensated with a rapid decrease of the vertical component reached in the bound, so that it reduced the time and space parameter values, and the angles of the hip and knee joints of the take-off leg, as well as of the CM in relation to the surface. By decreasing the hip and knee angles of the take-off leg, one can notice a lower tuck position and an increased bending over of the upper body, which emphasizes the amortization phase and the take-off phase. This enables reaching an adequate vertical and horizontal component of the CM movement in the bounce – off hands phase itself, which results in a successful realization of the flight phase.

The performance technique of the handspring salto forward to roll out demands a flight parabola, characterized by greater flight length and altitude, and is defined by the sharp angle of hands landing on the floor, lesser CM height and a 40° angle between the CM and the surface in the first hand-surface contact. The bound is followed by a shorter lunge, which lasts longer due to a larger distance between the take-off leg and the arms in the first hand-surface contact moment and an increase in the shoulder joint angles. During the flight phase, the CM height in the handspring salto forward tucked to roll out continuously grows only to finally reach the maximum height of 107.3 cm. In the exact push-off moment, there is a sudden angle reduction among the various body segments, which continues until the moment maximum flight altitude is reached. The rapid shortening of amplitudes among all the body segments and a tuck position during rotation is necessary to complete a full rotation of 360° around the transversal axis, taking into consideration that the landing begins with the first hand-surface contact. For this reason, the amplitude decrease among several body segments comes before reaching the maximum flight point and the complete tuck position is achieved after passing the vertical axis.

Horizontal CM velocities in the lunge phase, in placing hands on the surface, and during the bounce-off hands and flight phase, have high values with a tendency for growth, while they reach their maximum values at the moment of the take-off and the first hand-surface contact phase. Unlike the horizontal velocities, the vertical one rapidly decreases in the swing phase, the take off phase and the first hand-surface contact phase, so that in the push-off moment it suddenly rises and continues to rise until the maximum flight point of the CM is reached, where the complete tuck body position is achieved. After observing the horizontal velocities, it is obvious that a faster run and bound are crucial.

We can define the following kinematic parameters as the primary components, classified in three groups based on the execution phases of the handspring salto forward to roll out:

1) *Lunge phase*
   a. length of the lunge
   b. duration of the lunge
   c. CM height during the lunge

2) *Hand-support phase*
   a. CM height in the first hand-surface contact moment
   b. shoulder angle in the first hand-surface contact
   c. CM angle in the first hand-surface contact
   d. knee and hip angle in the first foot-surface contact after the lunge
   e. vertical and horizontal velocity in the first hand-surface contact

3) *Bounce-off hands phase*
   a. vertical CM velocity at the push-off moment
   b. duration of the bounce-off hands phase
   c. CM height at the push-off moment

The values indicating the significance of the handspring salto forward tucked to roll out as an exercise in training methods of the bounce-off hands phase were obtained by analyzing kinematic parameters essential in defining the correct technique of the bounce–off hands phase in executing acrobatic elements with forward body rotation and hand support. The correct execution of the bounce–off hands phase achieves the proper flight altitude, essential for learning more complex acrobatic elements with a high degree of difficulty, whose performance includes multiple rotations around the transversal and/or longitudinal axis.

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KINEMATIČKI MODEL ODRAZNE FAZE U NEKIM AKROBATSKIM ELEMENTIMA SA ROTACIJOM TELA PREMA NAPRED

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Cilj ovog istraživanja bila je upoređivanje kinematičkih parametara koji su ključni za definisanje pravilne tehnike faze odraza pri izvođenju akrobatskih elemenata s rotacijom tela prema napred, kao i definisanje kinematičkih parametara u fazi postavljanja ruku na podlogu, odraza i fazi leta, kao ključnim fazama u izvođenju akrobatskih elemenata s uporom rukama i rotacijom tela prema napred. Komparacija kinematičkih parametara ostvarena je na temelju snimaka premeta napred i premeta u salto u izvođenju gimnastičara vrhunskog svetskog kvaliteta. Upoređenje je izvršeno po pojedinim fazama izvođenja, a odnosi se na fazu postavljanja ruku na podlogu, fazu odraza i fazu leta. Procesiranje podataka izvršeno je pomoću Ariel Performance Analysis System (APAS, 1995). Analizom kinematičkih parametara koji su ključni za definisanje pravilne tehnike faze odraza pri izvođenju akrobatskih elemenata s rotacijom tela prema napred i uporom rukama o podlogu dobijene su vrednosti koje ukazuju da je premet u salto efikasna metodička vežba za obuku faze odraza. Pravilnim izvođenjem faze odraza ostvaruje se povoljna visina leta koja omogućava učenje akrobatskih elemenata viših i visokih težinskih vrednosti, koji u svoje izvođenje uključuju složenije i višestruke rotacije oko poprečne i/ili uzdužne ose tela.

Ključne reči: *faza oslonca, kinematički parametri, salto napred, rotacija napred.*