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Research article

KINEMATIC MODELING OF THE TECHNIQUE STALDER BACKWARD TO HANDSTAND ON THE UNEVEN BARS

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Abstract. *Optimizing the technique of successful performance is important for detecting different technique styles that occur in female gymnasts. The aims of this research were to define an optimal kinematic model of the Stalder backward to handstand on the uneven bars exercise, as well as factors that most greatly affect the successful performance of the selected exercise, performed at the 39th and 40th World Cups in Artistic Gymnastics in Maribor (SLO). The sample of participants consisted of eight female gymnasts who participated in the Finals and performed the above mentioned exercise. Kinematic parameters were determined by the use of the Ariel Performance APAS 3-D video system, and anthropometric 16 reference points with four body segments (foot, center of gravity of the body-CG, shoulder joint and head). CG was calculated based on the model presented by Winter in 2009. The results of the research defined the kinematic exercise model that requires four phases: 1) Upswing from a handstand position to balance the resistance front; 2) Downswing to upswing with clear support; 3) Lower vertical passing; 4) Swing to handstand position. Variability of the trajectory of referent points is necessary as an indication of the successful performance of the Stalder backward to handstand on the uneven bars technique. In the current research, the variability for the successful technique for CG trajectory values decreases from -0.767m to -1.045m, while the trajectory values of the shoulder point decrease from 0.689m to 0.488m under the axis of rotation. The information given could optimize the performance of other young gymnasts at all levels of performance.*

Key words: *gymnasts, female, modeling, uneven bars, kinematics, optimization*

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INTRODUCTION

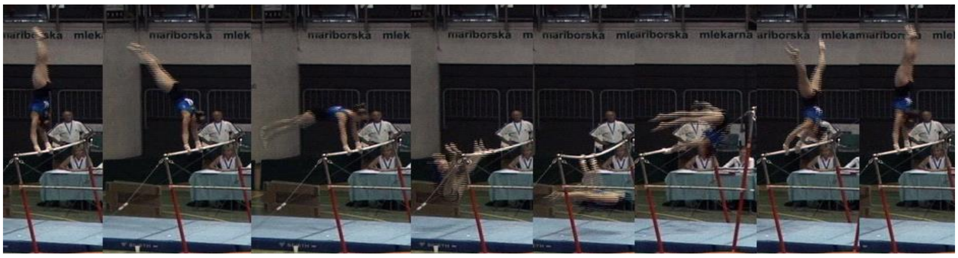
Uneven bars in women`s artistic gymnastics consists of a mount, number of circling skills, release and re-grasp skills and a dismount. The current trend in competitive uneven bars work is flowing routines toward high level difficulty skills. Many of the skills being performed are difficult skills, but also to perform skills with sufficient execution and amplitude it is necessary to ensure a swing for connections in the complete bar routine. To achieve a high score, gymnasts must perform difficult routines with high accuracy and proper technique. A biomechanical analysis of the movement is well suited to describe, develop and improve technique. Although many variables influence success, such as psychological or physiological factors, biomechanical considerations as reflected in correct or incorrect technique are crucial. The kinematic analysis of a certain kind of movement in artistic gymnastics is necessary for the rational and economical process of the analyzed movement (Brueggemann, Cheetham, Alp, & Arampatzis, 1994; Takei & Dunn, 1996; Kolar, Andlović-Kolar, & Štuhec, 2002; Tsuchiya, Murata, & Fukunaga, 2004; Hiley & Yeadon, 2013; Hanin & Hanina, 2009). When it comes to the uneven bars it should be noted that it is necessary to fully explore the techniques, first of all, of the basic movement. Movement on the bars is predominantly executed using two planes; movement in the sagittal plane such as the giant swing where the axis is the horizontal bar, and turning movements that occur on the transverse plane where the axis extends through the center of the gymnast’s body from the top of the head through to their feet (Pidcoe, Grehman, & McPherson, 2010). The Stalder backward from handstand to handstand (STAL) is a basic movement pattern in gymnastics, classified in the Code of Points (2005-2008) as a group of exercises with a "B" value, with circular movements as a "specific request" that the structure of the composition of the gymnasts’ performance requires. The first gymnast who carried out this element was Joseph Stalder, a gymnast from Switzerland, who won the gold medal in the combined horizontal bar exercise at the 13th Olympic Games in London, England, in 1948 (McWhirer, 1976). He was the first gymnast who performed the first "backward" Stalder. The Stalder family of movement on the uneven parallel bars is becoming a very important element in the gymnastics routines at the international level. Many elements of difficulty performed in women’s gymnastics are adapted from men’s gymnastics. The Stalder was primarily performed on the men’s horizontal bar, and then became a basic element in parallel bars routines. Marcia Frederick, a United States gymnast won the gold medal on the uneven bars at the 1978 World Championships in Strousseboure, France. Her routine contained many Stalder circles. According to Criley (1978) her victory was attributed to her daring risk, swing and personal technique. The Stalder actions involves a 360 degree rotation about a bar beginning and ending with the body in the handstand position. Within the course of the circle the gymnast attains an inverted dorsal hang position. Because of the changes in body position this movement combines the mechanics from both long and short circling actions (Kunzle, 1957). A Stalder starts in the handstand position with the gymnast moving backward and circling around the bar. It can be performed either with her legs straddled on either side of her arms or together inside her arms. Prassas (1994) studied the dynamics of the forward swing skills and the back toss on the parallel bars. The studies investigated the ability to generate angular momentum (Hiley & Yeadon, 2003a), the margin of error for dismounts (Hiley & Yeadon, 2013b) or the consistency of release and re-grasp skills (Hiley & Yeadon, 2007). Prassas (2002) systematized all the biomechanical studies that have been carried out in Men's and Women's Artistic Gymnastics. Hiley & Yeadon (2013) said that optimization criteria must reflect the performance outcome rather than the amount of effort required. When optimizing technique, minimizing effort or joint torque is often used as the basis of the score (or cost function). The increase in the 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.

The aims of this research were to define an optimal kinematic model of the Stalder backward to handstand on the uneven bars exercise, as well as factors that most greatly affect the successful performance of the selected exercise.

METHODS

The research sample consisted of eight female gymnasts who participated finals of the 39th and 40th World Cups in Artistic Gymnastics, both held in Maribor, and performed STAL.

At the 40th World Cup, the following 5 female gymnasts (born between 1988-1990, mean age 17±6 months) participated in the Final competition on the Uneven bars, and had one STAL in their gymnastic routine: Koster (NED), Li Ya (CHN), Palesova (CZE), Golob (SLO) and Šikulova (CZE). At the 39th World Cup the following 3 female gymnasts (born between 1988 and 1991, mean age: 17.5±6 months) in the Final competition on the Uneven bars, and had one STAL in their gymnastics routine: Erceg (CRO), Šikulova (CZE) and Bismpikou (GRE). Data processing was carried out according to the standards of the Ariel Performance 3D Video System (APAS) used for kinematic analysis, and anthropometric 16 reference points with four body segments (foot, center of gravity of the body-CG, shoulder joint and head). CG was calculated based on the model presented by Winter (2009). Our analysis only took into account the points and segments of the right side of the body that was closer to the camera lenses. The analysis was performed through several phases: frame grabbing, digitalization of the recorded videos and the reference points of the body, transforming the three-dimensional space and data filtering.



Kinogram 1 Stalder backward from hand to handstand by S. Bismpikou (GRE)

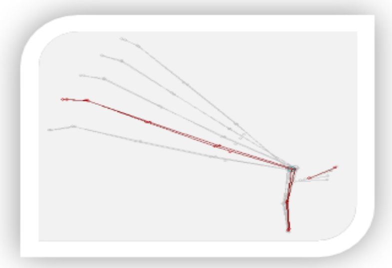
The Ethics Committee of the Faculty of Sport of the University of Ljubljana approved all experimental procedures according to the revised Declaration of Helsinki.

Gymnastic compositions on the uneven bars were recorded by two digital cameras DVCAM SONY DSR - 300pk that were located on the left and right sides' reconciliation at a right angle (900) relative to an axis that is normal to the direction of movement of the gymnasts and which passes through the middle of this apparatus (between the lower and higher bars) and rotation axis. The frequency of the camera was set at 50 Hz. The cameras were synchronized by an internal synchronous system. In order to define the field of measurement it was necessary to take calibration of the space with three frames of reference (2x1m3) leveled on the bars. Since the exercise was performed on the uneven bars, and the gymnasts performed on the right or left side of the bars (lower and upper bar), it was necessary that the different starting positions of the competitors be brought to the same level, i.e., the same starting position, so that a moderate space could be processed by the APAS software.

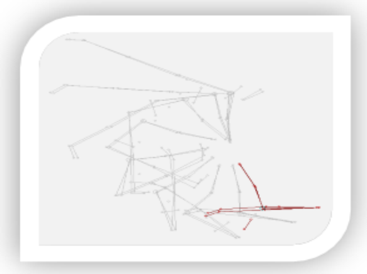
The exercise performed by Bismpikou (GRE) at the 39th World Cup was the basis for the absolute zero height and length for all other STAL exercises performed by other gymnasts (Kinogram 1). All of the performed exercises were moved into that absolute space, and center area was in the axis of rotation. The gymnasts' movements were performed in the same direction (the element performed on the uneven bars had the characteristics of a 2D movement, i.e., there was no significant movement along the mediolateral axis).

RESULTS

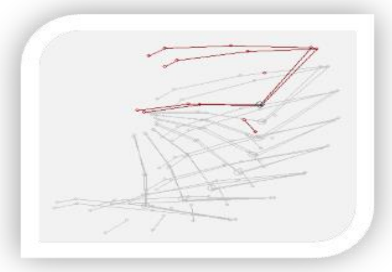
The results of this research contributed to the definition of the theoretical model, which requires four phases (Fig. 1): I Control gravity phase; II Gravitational phase; III Lower vertical passing with legs straddled; IV Swing to Handstand position.



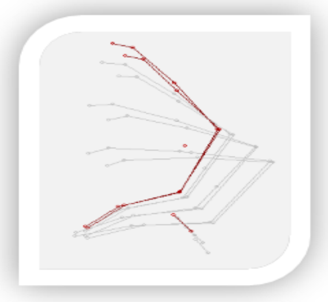
I. Control gravity phase (1-6th position)



II. Gravitational phase (7-38th position)



III. Lower vertical passing with legs straddled (39-51th position)



IV. Swing to Handstand position (52-60th position)

Fig. 1 Significant positions in the performance for kinematic modeling (representing gymnasts Li Ya)

DISCUSSION

The results of this research contributed to the definition of the theoretical model, which requires four phases. Gravity acting on the gymnast provides the force which causes sufficient angular momentum to allow the gymnast to circle the bar (Osborne, 1978). The normal component of angular momentum always acts toward the center of the curvature (Meriam, 1978). Accordingly to Barham (1978), the gymnast's CG is constantly changing position, being compelled to move in a curved path. Hay (1979) obtained the normal component in the equation, which was of great significance to the gymnast in the execution of circling movements. The circling movements (an) are represented by the equation:

$$An = V^2 / r + G \cos \Theta$$

V^2 – squared velocity; r- the radius of rotation; $G \cos \Theta$ – the mass of the object at any position

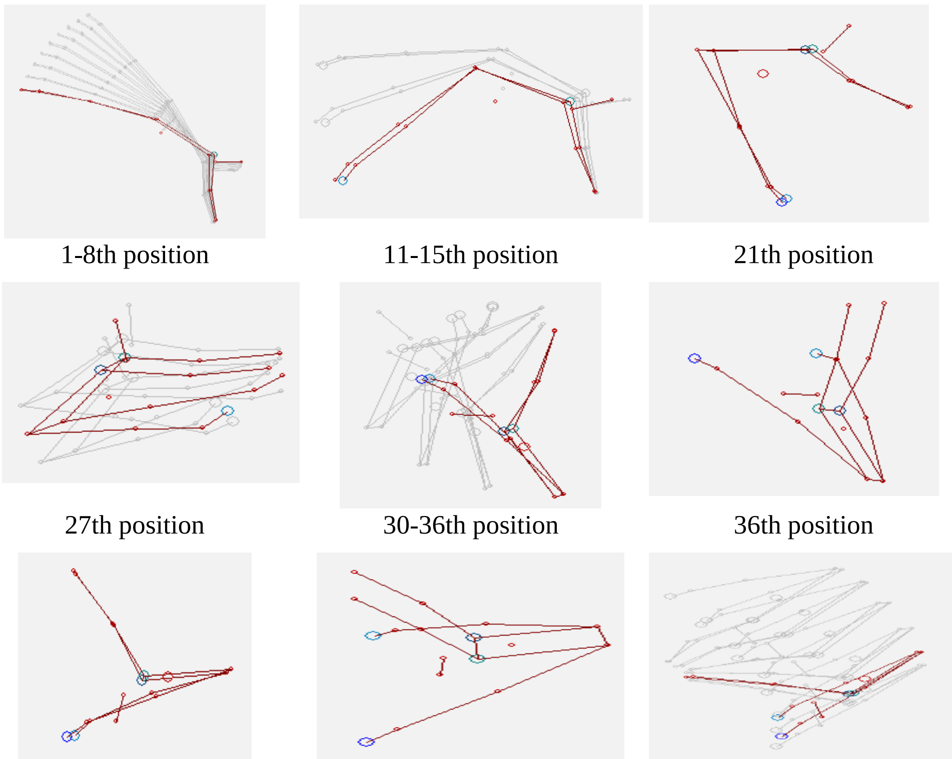
$$MO = m\, r^2 \omega$$

Mo – angular acceleration, m - the mass of the object; r^2 - squared radius of rotation; ω - angular velocity

Phase I - Control gravity phase begins from a handstand position and ends at the moment in the position of up front, when the shoulder deviation reaches the maximum position forward (in the 8th position when the axis of the shoulder joint forms an angle with the center of the support grasp). The handstand position on the Unbars is an unstable type of balance, considering the fact that two fundamental forces, the resultant force vector of the muscles and the force of gravity, are taken out of the previous equilibrium effects.

The characteristic of the upswing is that after the movement, two pendulum systems are created (Veličković et al., 2011; Petković et al., 2018) – the hanging pendulum and the supported pendulum. The first system that controls the body and legs while 'falling down' by rotating around the axis that is drawn through the center of the shoulder joint. In this system the position of the foot moves backwards, decreasing the angle between the torso and the legs. Another system that is made up of the arms and shoulders moves forward and the motion slows down. Most competitors end this phase in 4th (Bismpikou) to 8th position (Koster). In some competitors, these phases are not recognized because the point of the shoulder moves from the beginning of the movement backwards (Golob, Palesova, Šikulova).

Phase II starts with the movement of the shoulder point from the reverse to the back, and lasts until the lower vertical line passes. Competitors complete this phase between the 36th (Palesova) and 47th position (Golob). At the beginning of Phase II, the previous flow of movement continues until the moment when the point of the shoulder begins to rapidly increase the value (in a negative sense - bent headlong station), at which point the tops of the feet change their path (s12 = -1.369m), it cannot depart more approaching the rotation axis (Fig. 2, 11-15th position), to keep the body in the center of motion. The feet approach the bar until the point of the shoulder is located exactly above the body center (the x-axis values match). In this position, the hip points are furthest, and the hands are almost identical to the x-axis (Figure 2, 27th position). In real terms, the average shoulder and center point values match at 21st position with s = -0.47m. The position at which the CG, shoulders and head on the x-axis is 26, with mean values s = -0.67m, and then the tops of the feet are the most distant and reach their maximum. After this position, the feet begin to decrease the values (the negative values are increased) and the CG, the points of the shoulder and head approach the zero value on the x-axis (the negative values are reduced - Figure 2, 46th position). Immediately before the end of phase II, the foot ends the path by decreasing the values along the x-axis and starting the same path along the x-axis as other post-mortem points. The lower vertical is first passed by the hips, then the center of the body, and the other points. By passing the point of the shoulder through the lower vertical (beginning of phase III and positive values of this point on the x-axis), all points increase their values (Figure 2, 49th position). The last point that receives positive values on the x-axis is the foot. At the end of the second phase, there is a post-active transmission of the swing that allows the translator to magnify all the values of the trajectory of the observed points and allows the entry of the movement in phase III.



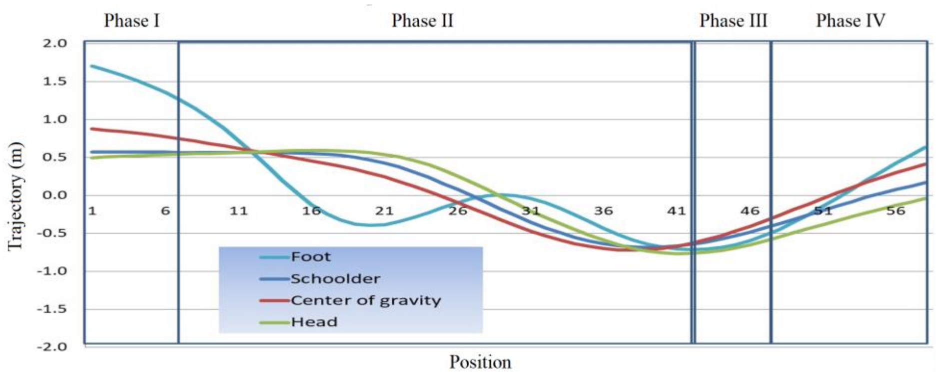
1-8th position | 11-15th position | 21th position

27th position | 30-36th position | 36th position

44th position | 46th position | 49th position

Fig. 2 The most important position in the performance of the STAL (gymnast Li Ya)

Phase III begins when the shoulder points pass through the lower vertical, and lasts until the moment of the start of the flow. This phase ends between the 52nd position (Li Ya) and the 60th position (Erceg). Phase IV begins with the overleaps of the bar and continues with the further extension of the arm, the extension in the shoulder joint, the extension and the adduction in the wrist to reach the end position (handstand position or moving to a new movement). At the beginning of the Stalder backward movement, the points of the shoulder usually do not change their values along the y-axis (and previously along the x-axis), located just above the grips (Graph 1). The point of the head rises slightly up (with minimal changes along the x-axis), while the center of gravity of the body (to a lesser extent as on the x-axis) and top of the feet (to a greater extent as on the x-axis) reduces its value - the descent down. The trajectory of the center of the first stage of the performance of the Stalder backward is not exclusively directed vertically downward, it moves backward and downward (Figure 3).



Graph 1 The relationship between the mean values of the trajectory of reference points

At the end of the first phase, all the points in the 12th position are crossed (sst=0.55m, sTt=0.588m, sra=0.563m, ste=0.573m), then the body enters the phase of the fall. From this position the values of the trajectory of the feet suddenly begins to fall to the 20th position (sst20= -0.394m), rapidly moving forward. The values of the shoulder and posture trajectory up to the 20th position have a uniform motion, and then suddenly begin to decrease (sra20 = 0.471m), i.e., the point of the shoulder moves down.

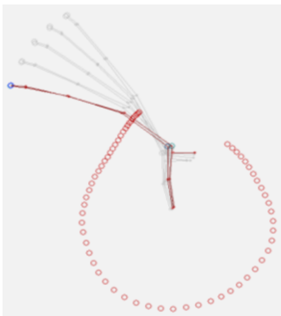
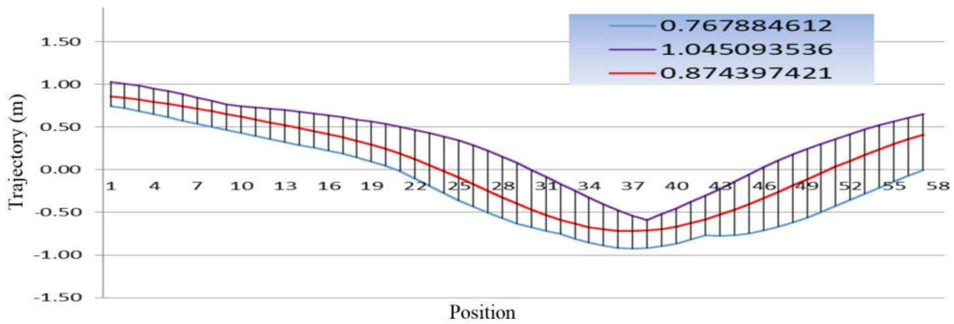


Fig. 3 Gymnast Li Ya (10th position)

At the beginning of the second phase, the feet pass under the CG and begin to move forward, the shoulder point starts to move vertically downward, in order to keep the body in the central movement. From the 20th to the 30th position, the legs are straddled in the inverted dorsal hang position (Petković, 2009). The foot trajectory values grow to their maximum when they form in the 30th position (sst30 = -0.002m) and they move downwards again and form their minimum in the 39th position (s39 = -0.638m). As soon as the hip point passes in front of the shoulder point and the CG, the feet start a second movement downwards. From positions 26-40, the values of the trajectory of all points are reduced to coincide in the 40th position (s40poz = -0.69m), except for the peak point of the lower value (s40poz = -0.75m). This reduction in the y-axis value is due to the effect of the anti-gravity force and post-active transfer on the swinging. Entering the third phase of the shoulder and the CG increase, the values on the above axis (the movement starts upward), due to the fact that the posterior transmission of the swing from the open part of the kinetic chain (upper body) to the closed (arm and shoulder belt). After several positions, when the point of the hips comes to a position above the point of the shoulder, the movements begin to rise and the foot peaks. Lees (2002) suggested that technique can be categorized into different styles, general or specific; both of which would influence the selection process. Different styles of exercise technique depend on several parameters, and the most important are the body height and weight of the gymnastics and the speed-muscular properties of the technique of performance. Unique technique style is a specialty of gymnatics.



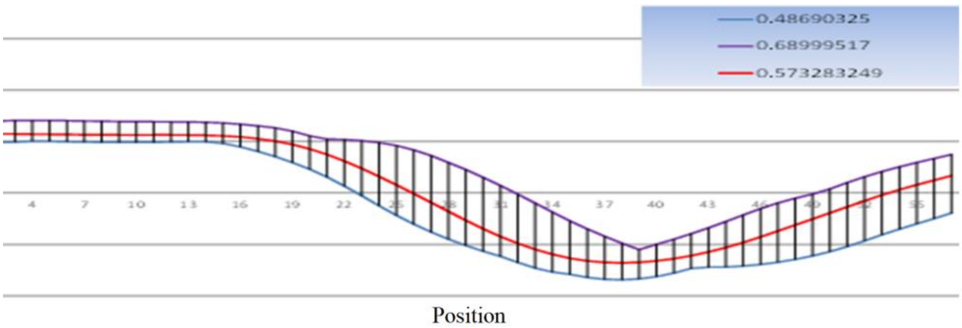
Graph 2 Variability of the CG in the y-axis

Variability of the trajectory of referent points is necessary as an indication of the successful performance of the STAL technique. With an expert assessment (Kolar et al., 2002; Petković, 2009; Veličković et al., 2011) we decided to monitor the variability of the referent points – CG and shoulder point along the y-axis. Graph 2 shows maximum, minimum and mean value of variability of the referent point CG along the y-axis. At the beginning of the movement, there is a low variability of CG. Variability decreases from the start to increase by the end of the motion. Waves that are interesting for analysis are related to the period of movement from positions 22 to 37, when there is decreased variability (approximately 1m from the axis of rotation). From position 37 when the point of the shoulder moves up, the variability of CG slowly grows as the CG returns to its handstand position. From the 22nd to the 34th position, the legs are straddled in the inverted dorsal hang position (Petković, 2009). The CG trajectory values decrease to a minimum value of maximum validity of a successful technique when they form in the 37th position (sst37 = -0.767m) and they move downwards again and form their minimum validity of a successful technique in the 38th position (s38 = -0.923m). The purple line presents the trajectory of the maximum value of the execution of successful STAL techniques. The maximum value of the trajectory of the CG movement is -1.045m. The blue line presents the trajectory of the minimum value of the execution of successful STA techniques. The minimum value of the trajectory of the CG movement at the decreased point is -0.767m. The red line presents the trajectory of the mean value of the execution of successful STAL techniques. The mean value represents the ideal value of the trajectory of the CG movement in successful STAL techniques. The mean value of the trajectory of the CG movement at the decreased point is -0.874m (the minus sign indicates that the values are below the axis of rotation).

Table 1 Intercorrelation matrix trajectory of the CG along the y-axis for STAL

	Erceg	Sikulova 1	Sikulova 2	Bismpikou 1	Bismpikou 2	Koster	Li Ya	Palesova	Golob	Sikulova 3
Erceg	1.000									
Sikulova 1	.799**	1.000								
Sikulova 2	.863**	.993**	1.000							
Bismpikou 1	.672**	.982**	.954**	1.000						
Bismpikou 2	.611**	.964**	.926**	.997**	1.000					
Koster	.877**	.988**	.999**	.944**	.915**	1.000				
Li Ya	.915**	.971**	.992**	.911**	.875**	.995**	1.000			
Palesova	.566**	.947**	.903**	.990**	.997**	.892**	.847**	1.000		
Golob	.999**	.778**	.846**	.647**	.585**	.861**	.902**	.539**	1.000	
Sikulova 3	.762**	.998**	.985**	.991**	.977**	.979**	.957**	.964**	.741**	1.000

High values of the trajectory of the centar of gravity along the y-axis (.778 - .998) were obtained for the intercorrelation of the kinematic parameters (Table 1). Their intercorrelation is large, with a 1% risk factor the connection between the trajectories of the CG between the gymnasts who performed the Stalder backward to handstand along the y-axis.



Graph 3 Variability of the shoulder trajectory along the y-axis

Graph 3 shows the maximum, minimum and mean value of variability of the shoulder point along the y-axis. At the beginning of the movement, there is a low variability because of the shoulder distance on the handstand position from the axis of rotation. Variability decreases from the start to increase by the end of motion. The range of motion of the trajectory of the shoulder point along the y-axis acts as a center of gravity. In Table 3 the purple (highest) line presents the trajectory of the maximum value of the validity of successful STAL techniques. The blue line (the lowest) presents the trajectory of the minimum and the red line presents the trajectory of the mean value of the validity of successful STAL techniques. The maximum value of the trajectory of the shoulder point is 0.689m. The trajectory values decrease to their mean value of validity of a successful technique when they form in the 38th position (sst38 = 0.573m) and they move downwards again and form their minimum of minimum validity of a successful technique in the 38th position (s38 = 0.488m).

Table 2 Intercorrelation matrix trajectory for shoulder point along the y-axis for STAL

	Erceg	Sikulova 1	Sikulova 2	Bismpikou 1	Bismpikou 2	Koster	Li Ya	Palesova	Golob	Sikulova 3
Erceg	1.000									
Sikulova 1	.781**	1.000								
Sikulova 2	.845**	.993**	1.000							
Bismpikou 1	.672**	.987**	.963**	1.000						
Bismpikou 2	.640**	.977**	.949**	.996**	1.000					
Koster	.831**	.996**	.999**	.970**	.958**	1.000				
Li Ya	.880**	.982**	.995**	.940**	.920**	.993**	1.000			
Palesova	.587**	.959**	.923**	.988**	.996**	.934**	.891**	1.000		
Golob	.999**	.789**	.851**	.681**	.649**	.837**	.886**	.598**	1.000	
Sikulova 3	.755**	.999**	.988**	.992**	.986**	.992**	.972**	.970**	.763**	1.000

In Table 2 the values of the trajectory of the shoulder point along the xy-axis (587 - .999) are presented. Their intercorrelation is range, from an average to large correlation. The significance level is 0.01 and it can be interpreted with a 1% risk factor of connection of the movement trajectory between the gymnasts who performed the Stalder backward to handstand along the y-axis.

The Stalder backward to handstand on the uneven bars belongs to a group of basic movements. Before we teach a STAL, the gymnasts must have sufficient technical knowledge of the free hip circle – more times in a row – to support (Karacsony & Čuk, 2015, 46). Earlier studies that determined the optimal model of performance of the Clear hip circle to Handstand (Veličković et al., 2011; Kolar et al., 2002; Petković, Veličković, & Stanković, 2006, Veličković, Kolar, & Petković, 2006; Petković et al., 2018) have shown key positions in the successful performance of the element. Based on the movement of the referent points in these case studies – the center of gravity and shoulder point, a successful STAL technique must stand in the range of validity values: the CG trajectory values decrease from -0.767m to -1.045 below the axis of rotation. The trajectory values of shoulder point decrease from 0.689m to 0.488m under the axis of rotation. A kinematic model defined in this way as a case study evaluating theoretical characteristics will promote the process of creating a methodological training procedure which should facilitate the process of learning exercises through the analysis of individual phases. Information given in the form of a case study could optimize the performance of other young gymnasts at all levels of performance. This case study defines the necessary parameters of the successful implementation of the Stalder circle. “There is a need for a practical and research-based tool to cope with difficulties in the performance of top-level athletes as a special group of expert performers with extensive experience in intensive training and competition” (Veličković et al., 2011). Thorough analysis of the STAL will not only aid coaches in training female gymnasts for this specific performance, but it will also identify the critical kinematic parameters in the execution so that gymnasts may begin to master these basic skills earlier in their careers.

CONCLUSION

The optimal kinematic modeling of the STAL technique highlighted the theoretical characteristics of the key positions and the influence on the technical execution. This is probably the first study that theoretically explained the optimal phase in the movement of the gymnastic element in top-level female gymnasts. New studies should explain the use of energy sources during movement, so that the kinematics analysis of the movement is supplemented.

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KINEMATIČKI MODEL VEŽBE ŠTADLER KOVRTLJAJ UNAZAD NA DVOVISINSKOM RAZBOJU

Optimizacija tehnike uspešnog izvođenja elementa je važna za otkrivanje različitih stilova tehnike koji mogu da se pojave u izvođenju kod gimnastičarki. Cilj ovog istraživanja bio je da se definiše optimalni kinematički model vežbe Štalder kovrtljaj unazad na dvovisinskom razboju, kao i faktori koji najviše utiču na uspešno izvođenje odabrane vežbe, izvedene na 39-tom i 40-tom Svetskom kupu u sportskoj gimnastici u Mariboru (SLO). Uzorak ispitanika sačinjavalo je osam gimnastičarki koje su učestvovale u finalu i izvele gore navedenu vežbu. Kinematički parametri su određeni upotrebom Ariel Performance APAS 3-D video sistema, i 16 antropometrijskih, referentnih tačaka četiri segmenta tela (stopalo, težište tela-TT, zglob ramena i glava). TT je izračunat na osnovu modela koji je predstavio Vinter 2009. godine. Rezultati istraživanja su definisali model kinematičkog izvođenja koji se uslovno može podeliti u četiri faze: 1) odnjih iz stava u uporu do položaja vage u uporu prednjem; 2) spad iz upora prednjeg do visa uznetog raznoženjem van; 3) prolazak donje vertikale u visu raznožno van; 4) dolazak u stav u uporu. Varijabilitet trajektorije referentnih tačaka je neophodan kao pokazatelj uspešnog izvođenja Štalder kovrtljaja unazad na dvovisinskom razboju. U aktuelnom istraživanju varijabilitet parametra za uspešnu tehniku izvođenja trajektorije kretanja težišta tela se umanjuje sa -0.767m na -1.045m, dok se putanja vrednosti tačke ramena umanjuje sa 0.689m na 0.488m ispod ose rotacije pritke. Date informacije mogu da pomognu drugim, mladim gimnastičarkama prilikom optimalnog izvođenja vežbe, na svim takmičarskim nivoima.

Ključne reči: *gimnastičarke, modelovanje, dvovisinski razboj, kinematika, optimizacija*