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Original research article

PREDICTION OF THE SUCCESS OF THE BASKET TO HANDSTAND ON PARALLEL BARS BASED ON KINEMATIC PARAMETERS – A CASE STUDY

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Abstract. *The aim of this research was to determine which kinematic parameters have the most important influence on success in performing the basket to handstand maneuver. The research sample consisted of fifteen attempts of the basket to handstand performed without a mistake and fifteen attempts performed with a medium or a big mistake according to the regulations. All the attempts were performed by a European and World Champion on the parallel bars, while the success of the attempts was scored by three internationally accredited sports gymnastics judges. The obtained results showed that the success of the analyzed element could be predicted based on the angular velocity of retroflexion in the shoulder joint, the shoulder joint center velocity and the angle of the shoulder joint during the first phase, then based on the body center of gravity (bcg) velocity, shoulder point velocity and the angle of the hip joint in the second phase and bcg velocity, angle of the shoulder joint and hip joint, and the size of the angular velocity of anteflexion in the shoulder joint in the third phase. The research model could, in general, be applied to all sports where the performance technique has an important influence on the final result.*

Key words: *artistic gymnastics, technique, kinematic analysis, prediction.*

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INTRODUCTION

A model of successful routine for competitors in artistic gymnastics consists of the most complex coordination elements and their successful execution. A gymnast will be more successful if he has the most complex coordination elements in his exercise (elements of D, E, F and G level of difficulty) and if he performs his exercises with the smallest number of technical and aesthetic mistakes possible. For this reason, examining the techniques of the most complex elements and mistakes made during the performance present an interesting problem for research in sports gymnastics. A rational and economical process of teaching and perfecting the elements requires detailed analysis, particularly related to learning details, which are not readily available to the visual inspection of the coach and the kinesthetic receptors of the gymnast performing the element. Insight into the hidden techniques of an element cannot be obtained without a kinematic analysis. Research in the field of kinematic analysis of a certain kind of movement is becoming more and more frequent in artistic gymnastics; particularly as the obtained information enables a more rational and economical instruction and acquisition of the analyzed movement (Brueggemann, Cheetham, Alp, & Arampatzis, 1994; Takei, 1998; Yeadon & Brewin, 2003; Hiley & Yeadon, 2007; Heng, 2007; Hanin & Hanina, 2009).

The apparatus that offers all competitors an equal possibility of achieving top results (not demanding, in the sense of training conditions) are the parallel bars. Success on this apparatus largely depends on knowing all the details of complex element techniques, therefore many research papers are focused on this feature. However, very few research papers deal with the kinematic analysis of the parallel bars elements. Linge, Hallingstad, & Solberg (2006) dealt with the modeling of the parallel bars in Men's Artistic Gymnastics. Prassas & Ariel (2005) dealt with the kinematics of giant swings and the back toss on the parallel bars (Prassas, 1994), as well as Tsuchiya, Murata, Fukunaga (2004) who dealt with the kinetic analysis of the same element. The double back salto dismount from the parallel bars was studied by Gervais & Dunn (2003). Additionally, there were many research papers which dealt with the comparative study of two similar elements. Kolar, Andlovic-Kolar, & Štuhec (2001) conducted comparative analysis of selected biomechanic characteristics between a support backward swing and support swing for the 1 1/4 straddle-picked forward salto on the parallel bars. Furthermore, there are research papers which focus on the study of the new elements. A detailed study of this kind was carried out by Čuk (1996), with the aim of determining the procedure used to prepare a new exercise, from the initial idea to its realization. The exercise used as the example is the "dismount with a clenched flip forward on the horizontal bar sideways".

The basket to handstand on the parallel bars (Figure 1) belongs to the category of difficult elements which are very interesting for further research (Figure 1).

This is the element which, by its coordination complexity, can be classified as the element belonging to the "D" difficulty group, and which, by its specific aspect, belongs to group IV of the elements on parallel bars (underswings). The above named element has become so popular that it is performed in all European and World Championship finals, as well as in the Olympic Games. There is no top competitor on parallel bars who does not perform basket to handstand as an integral part of his exercise. The reason for the high popularity of the basket to handstand is not only obtaining points for difficulty (difficulty values – D score - 0.40 points) and fulfilling a specific requirement (element groups – underswings – 0.50 points). The other important reason is that this element is highly promising, since it has the possibility of advancing into more complex elements in the same structure group (the basket with 1/2 and 1/1 turn to handstand, the basket with immed. straddle cut to support, the basket with inlocation – el grip and hop to handstand – Cucherat, Basket to one rail handstand - Chiarlo).

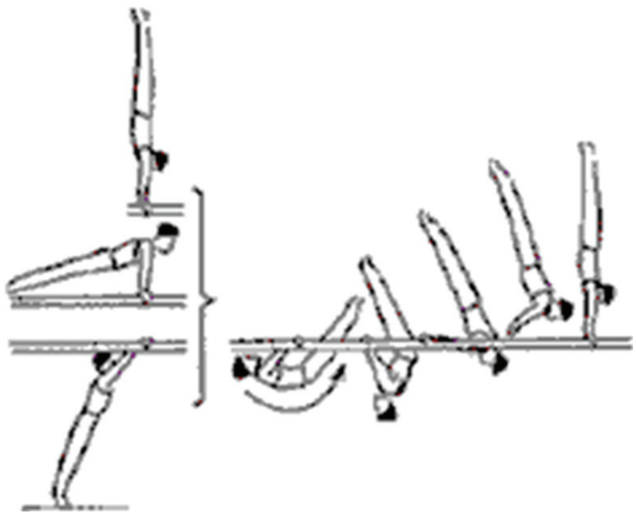


Fig. 1. Basket to handstand on the parallel bars
(Federation Internationale de Gymnastique-FIG, 2013).

From the abovementioned reasons, there is a need for a more detailed research of this element, as well as for obtaining new information which will enable a more successful and economical implementation of this element. Previous research focused on the Basket (felge) to handstand mount on the parallel bars (Takei & Dunn, 1996). The mount starts from a standing position from which the gymnast jumps into the swing. The performances of 26 national gymnasts were separated into two groups based on a score criterion and then analyzed. It was found that better performances were associated with a higher mass center position and vertical velocity at release. It was also observed that in the poorer performances the gymnasts over-rotated before releasing the bars, which led to a poor body position on re-grasp. Being over-rotated at release would result in the gymnast re-grasping the bars with a larger angle between the body and the vertical axis. To achieve the handstand from this position, the gymnast would be required to do the press to handstand, incurring deductions from the judges.

The technique depicted in the Code of Points (FIG, 2013) closely resembles to backward clear circle to handstand as performed on the high bar (Figure 1). During this technique, the gymnast maintains the hip flexion angle throughout most of the circle, in particular while he is below the bars (Figure 1). It has been recommended that this technique be used during the initial stages of learning the felge (Davis, 2005), presumably because it is less demanding of the young gymnasts. However, the technique used by many senior gymnasts more closely resembles a "stoop stalder" (Davis, 2005). As the gymnast passes beneath the bars, a deep pike position (large hip flexion angle) is adopted, from which he rapidly extends passing through release and into the final handstand position.

Veličković et al. (2011), and Veličković, Kolar, & Petković (2006), determined a kinematic model of the actual element. Veličković et al. (2005), dealt with the problem of the differences between the basket and basket with ½ turn to handstand on the parallel bars.

Recent research has dealt with the optimization of the techniques of exercise performance, some of which are specifically related to the optimization of the basket to handstand technique (Hiley, Wangler & Predescu, 2009). Two male gymnasts each performed nine trials of the felge from handstand to handstand while data were recorded by an automatic motion capture system. The highest and lowest scoring trials of each gymnast, as determined by four international judges, were chosen for further analyses. The technique used by each gymnast was optimized using a computer simulation model so that the final handstand position could be achieved with straight arms. Two separate optimizations showed different techniques identified in the coaching literature which were used by gymnasts. Optimum simulations resulted in improved performances through a combination of increased vertical velocity and height of the mass center at release. Although the optimum technique which was closer to the gymnasts' own technique was more demanding in terms of the strength required, it offered the potential for a more consistent performance and future developments in skill complexity.

The top class parallel bars competitor had the basket to handstand in his gymnastic exercise, but during the performance of this element, he reproduced a medium and big technical mistake, which had a large influence on his final score and results at important competitions. The visual inspections performed by the coach and motor sensation of the gymnast himself were not helpful in the detection of mistake cause. In order to solve the above mentioned problem, the gymnast's movement was analyzed scientifically, i.e. a kinematic and regression analysis were applied with the aim of determining the most important predictors of the successful performance of the basket to handstand.

THE METHOD

The sample of participants consisted of one competitor, a member of the Slovenian senior national gymnastics team, and a parallel bars multiple medals winner in World and European championships from 1997 till the present. On all the official competitions, from 2012 onwards, the contestant has performed the parallel bars element which is the subject matter of this research – the basket to handstand technique. The participant, as an elite gymnastics competitor, according his anthropometric characteristics, fits the model of the world's top gymnasts (body height 165 cm, body weight 63 kg). The Ethics Committee of the Faculty of Sport, University of Ljubljana, approved all experimental procedures according to the revised Declaration of Helsinki.

In the experimental conditions (during training) the above mentioned competitor attempted several baskets to handstand, the success of which varied. All the repetitions were recorded using two synchronized video DVCAM - SONY - SR - 300 PK cameras, with a frequency of 50 Hz. Before the actual recording, and for the purpose of precise space calibration, two reference frames ($1m^3$ each) were positioned in the middle of the parallel bars, and recorded using the cameras (Figure 2).

The performance of each attempt was scored by three internationally accredited judges (FIG - BREVET) in accordance with the current scoring system of the "E" jury (jury scores the performance and technical aesthetic mistakes) in sports gymnastics (FIG, 2013). Ten attempts, evaluated as successful (without technical mistakes) and ten attempts, evaluated as unsuccessful (with medium or big mistakes) were separated for the purpose of further research. In order to determine the kinematic parameters and present the kinogram, an Ariel Performance 3D video system was used for the kinematic analysis (APAS). As part of the kinematic analysis, a digitalization of the 15-segment competitor model was carried out. As the performed element had the characteristics of a two-dimensional movement, there was no significant movement along the mediolateral (z) axis.

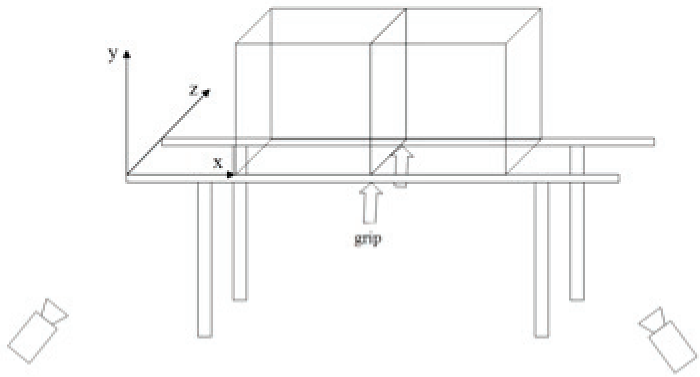


Fig. 2. Calibration space.

The set of criterion variables consisted of kinematic parameters with the biggest correlation with the judges' score of the analyzed movement: y location of the bcg and of the tip of the toes at the instant of re-grasping (TYBCG162 and TYFOO162, respectively) and the angle of the shoulder joint at the moment of re-grasping (ANSHO162 - Figure 3).

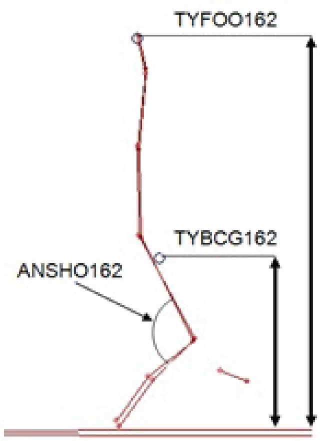


Fig. 3. The position of re-grasping (1.62s - movement) and the criterion variable.

The set of predictor variables consisted of kinematic parameters which, based on an expert analysis, correspond to the most important representatives of movement in specific phases, such as: the bcg distance from the center of rotation (DBCGCR); bcg velocity (VBCG) as the representative of velocity of the total system consisting of two pendulums, a supported and suspended one; the velocity of the shoulder joint center (VSHOL) as representative of suspended pendulum angular velocity (suspended pendulum implies hands with the hand joint as a supporting point); foot tip velocity (VFOOT); angle of the shoulder joint (ANSHO); angle of the hip joint (ANHIP); angular velocity in the shoulder joint (AVSHO) as the representative of angular velocity of the suspended pendulum (a suspended pendulum implies the gymnast's body with a suspense point in the shoulder joint); the angular velocity of the hip joint (AVHIP).

Values of the above stated parameters, as predictor variables, were obtained for the following passing positions:

Representatives of Phase I (the swing forward from handstand to support scale) when the supported pendulum moves forward: the positions when the shoulder point and grasping make an angle of 75deg (Time=0.14s) and 65deg (Time=0.30s), see Figure 4.

Representatives of Part I, Phase II (the downhill backward from the support to the inverted pike hang) when the supported pendulum starts moving backwards, up to the moment of the loss of contact with the bars: the positions when the shoulder point and grasping make an angle of 75deg (Time=0.46s) and 90deg (Time=0.58s).

Representatives of Part II, Phase II, from the moment the supported pendulum leaves the support surface up to the time at which the shoulder point reaches its lowest position and when the maximum flexion in the hip joint is reached: the positions when the shoulder point and grasping make an angle of 135deg (Time=0.70s), 180deg (Time=0.82s), 225deg (Time=0.92s) and 270deg (Time=1.06s).

Representatives of Phase III (the underswing - anti-gravitational phase), the period of performing the underswing: the positions when the shoulder point and grasping make an angle of 315deg (Time=1.22s) and 360deg (Time=1.36s).

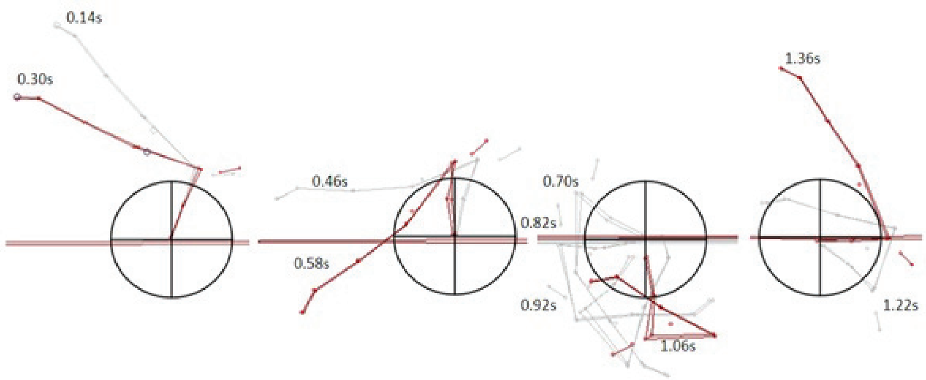


Fig. 4. The positions as representatives of the movement phases.

The data processing included determining the correlation between the criterion variables and judges' score by calculating Pearson's correlation coefficient. After that, a comparative parametric procedure was applied, and it was marked as a step-by-step multiple regression analysis (STEPWISE). During this procedure, the same criterion for ending the regression analysis was used (Stepping Method criteria – Use probability F: Entry – 0.05, Removal – 0.10). This way of separating the predictor variables enabled the prediction of criteria with the clarified variance and the least possible number of significant predictor variables. Such a regression analysis influenced the subject and aim of the research, as well as the sample of participants, attempts and variables. The following was calculated: the multiple correlation coefficient of the criterion variable and the predictor system (R), the percentage of explained variants (R2×100), the F test (F) and the importance of the multiple correlation coefficient (P), the standard partial regression coefficient of every predictable variable with a criterion (Beta), the t-test (t) and the importance of the Beta coefficient (p), a zero-order (r) and partial correlation (r part).

Statistical data processing was performed using the software package SPSS v. 16 for Windows.

THE RESULTS

Justification for the choice of the criterion variables was determined based on the values of the criterion variables correlation coefficient and the judges' scores. The results are shown in Table 1.

Table 1. Pearson Correlation of the judges' scores and criterion variables.

	TYFOO162	TYBCG162	ANSHO162
JUDGE "E" SCORE	,885	,837	,869
Sig. (2-tailed)	,000	,000	,000

All the correlation coefficients are high and statistically significant, which justifies further use of the criterion as a representative of movement success.

Phase I of the basket to handstand lasts from the beginning of the movement (handstand) to the moment of maximum deflection of the shoulder point forward. Figure 5 shows the correlation between the successful and unsuccessful attempt in the Phase I.

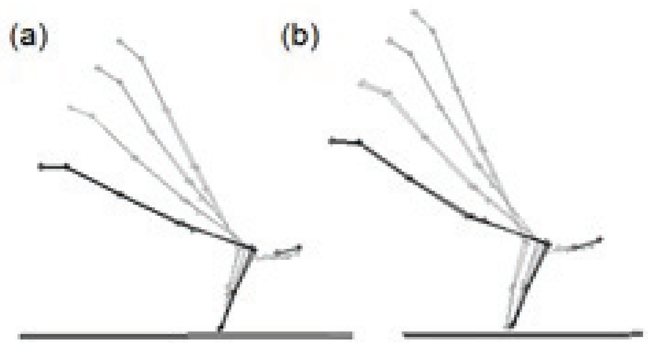


Fig. 5. Phase 1: The swing forward from the handstand to support scale; (a) successful, (b) unsuccessful.

Phase II starts from the support scale position, by moving the supported pendulum (hands-head system) backwards, rotating around the grasping axis and lasts until the beginning of the swing forward from an inverted pike hang – underswing, i.e. till the beginning of the extension in the hip joint. Figure 6 shows a comparison of a successful attempt and an unsuccessful attempt.

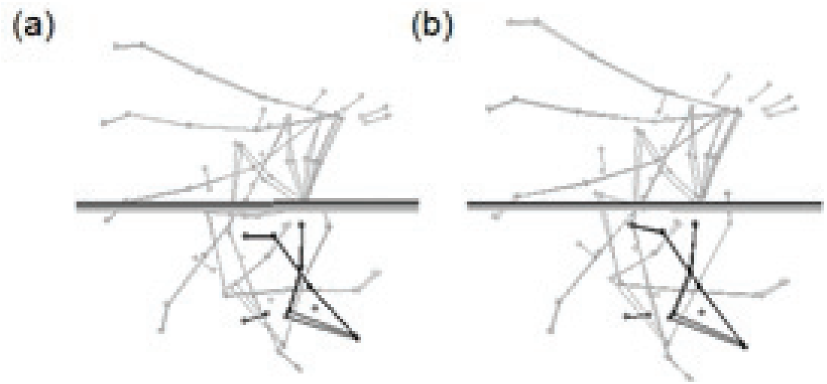


Fig. 6. Phase 2: the downhill backward from support to the inverted pike hang; (a) successful, (b) unsuccessful.

Phase III lasts from the beginning of the hip joint extension to the moment of leaving the bars. Figure 7 shows a comparison of a successful attempt and an unsuccessful attempt.

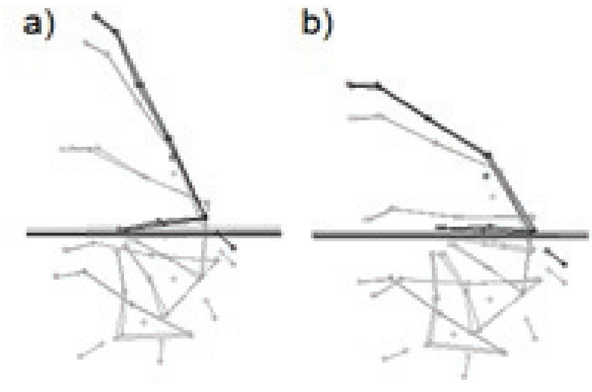


Fig. 7. Phase 3: Forward swing from inverted pike hang – underswing; (a) successful, (b) unsuccessful.

Phase IV lasts from the beginning of the support-less phase till the end of the movement. Figure 8 shows a comparison of a successful attempt and unsuccessful attempt. This phase has not been included in the analysis of movement success, since it represents the consequence, i.e. the result of all the effects of the three previous phases.

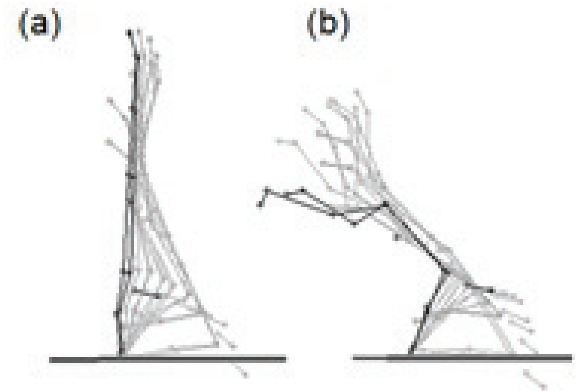


Fig. 8. Phase 4: the push up to handstand: (a) successful, (b) unsuccessful.

Table 2. The Linear Regression (method: stepwise) – Dependent Variable TYFOO162.

Predictors	r	r part.	Beta	t	p
AVSHO014	,341	,578	,305	2,832	,012
AVSHO136	,781	,567	,395	2,754	,014
ANSHO136	,778	,679	,526	3,700	,002
R = ,906 R^2×100 = 82,1% F = 24,506 P=,000					

Table 2 clearly shows that the separated model of predictor variables is in a high and statistically significant multiple correlation with a dependent - criterion variable (TYFOO162 - Figure 3). The system of separated predictor variables explains 82.1% of the criterion variability, while the other parameters, which are not included in the model, are responsible for the remaining 17.9%. All of the separated predictors have a statistically significant influence on the first criterion variable (foot top height at the moment of re-grasping the bars – TYFOO162), the dominant one being the weight of the shoulder joint angle at the moment the shoulder point reaches bar level (ANSHO136 - point in time 1.36s - Figure 4), then the angular speed of the shoulder joint at the same point in time (AVSHO136) and angular velocity in the shoulder joint at the beginning of the movement (AVSHO014).

The method of the stepweis regression analysis for the second criterion variable (TYBCG162 – bcg height at the moment of re-grasping the bars – Figure 3) separated the model of six predictors (Table 3) which, as the predictor systems as a whole have a very high (R=.987) and statistically significant (significance level less than P=0.01) influence on criterion variability. The system of predictors explains 97.5% of the criterion variability. The angle of the hip joints at the moment when the shoulders reach bar level at the end of Phase III (ANHIP136) has the biggest statistically significant influence on the criterion variable, then the angle of the shoulder joint at the same point in time (ANSHO136) and the velocity of the body's center of gravity in Phase III of the movement (VBCG136 and VBCG122). The hip joint angle at the moment of passing through the lower vertical (ANHIP106) and the velocity of the shoulder joint in the first part of Phase II, after the shoulder point leaves the support surface (VSHOL070) have a negative and statistically significant influence.

Table 3. The Linear Regression (method: stepweis) – Dependent Variable TYBCG162.

Predictors	r	r part.	Beta	t	p
VSHOL070	,359	-,730	-,302	-3,851	,002
ANHIP106	,389	-,626	-,180	-2,892	,013
VBCG122	,810	,783	,310	4,536	,001
VBCG136	,212	,768	,225	4,327	,001
ANHIP136	,784	,926	,713	8,818	,000
ANSHO136	,740	,900	,399	7,459	,000
R = ,987	$R^2 \times 100$ = 97,5%		F = 84,058		P=,000

The value of the multiple correlation coefficient of R=.983 (Table 4) shows that the separated predictor model has a very high and statistically significant (P=.000) influence on the third criterion variable (the shoulder joint angle at the moment of re-grasping the bars – ANSHO162 – Figure 3). The percentage of the explained variability of the criterion variable is also very high - 96.6%. Kinematic parameters from Phase III, such as bcg velocity (VBSG122) and shoulder joint angle (ANSHO136) have the biggest, statistically significant influence on the criterion variable. Four other variables which mostly represent Phase I of the movement have a smaller, yet statistically significant influence on the criterion variable.

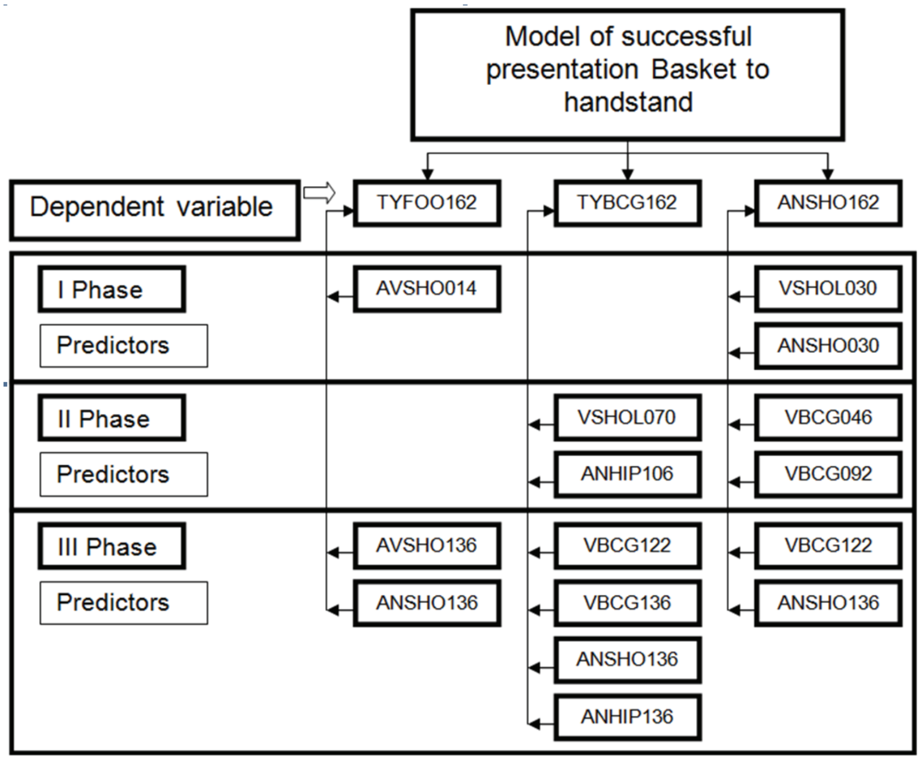
Table 4. The Linear Regression (method: stepweis) – Dependent variable ANSHO162.

Predictors	r	r part.	Beta	t	p
VSHOL030	,452	,608	,160	2,762	,016
ANSHO030	,386	,658	,178	3,147	,008
VBCG046	-,100	,718	,215	3,715	,003
VBCG092	,161	,797	,254	4,766	,000
VBCG122	,791	,930	,629	9,127	,000
ANSHO136	,728	,889	,424	7,012	,000
R = ,983	$R^2 \times 100$ = 96,6%		F = 61,520		P=,000

DISCUSSION

In order to make the discussion more clear, the model of a successful performance of the basket to handstand is shown (fi).

The successful performance of the basket to handstand can be predicted based on three kinematic parameters: angular velocity of the extension in the shoulder joint (AVSHO014), then the shoulder joint center velocity as the representative of the supported pendulum deflection velocity (VSHOL030) and the angle of the shoulder joint (ANSHO030) at the moment of reaching the maximum forward deflection of the supported pendulum (Figure 4). During successful attempts, the velocity of shoulder point movement (of the supported pendulum) forward and the angular velocity of retroflexion in the shoulder joint (suspended pendulum rotation velocity) are slower. The average velocity value of the shoulder point for a period of 0.14 s is 0.39 m/s for successful and 0.45 m/s for unsuccessful attempts. Successful attempts also imply a bigger angle in the shoulder joint at the moment of reaching the maximum amplitude of the supported pendulum forward. During successful attempts, this parameter is 88deg, while during unsuccessful attempts it is 86deg. The above stated implies that successful attempts are characterized by a more controlled movement phase I (Figure 5), i.e. by a slower and more controlled swing forward from the handstand to support scale and that the next phase (downhill backward from support to the inverted pike hang) starts with a more open shoulder joint angle.



Graph 1. The model of a successful performance of the basket to handstand.

The successful performance of the basket to handstand can be predicted based on four kinematic parameters in movement phase II: BCG velocity at the moments of supported pendulum moves backward, but before the loss of the support surface (VBCG046 – Figure 4 and 6) which is, on average, smaller during successful attempts (successful – 1.72 m/s; unsuccessful – 1.81 m/s), shoulder point velocity after leaving the equilibrium position (VSHOL070) which is bigger during successful attempts (successful – 3.90 m/s; unsuccessful 3.75 m/s), bcg velocity after the shoulder point comes under the bar level (VBCG092) which is now bigger during successful attempts (successful – 3.05 m/s; unsuccessful – 2.92 m/s) and, in the end, the hip joint angle at the moment of passing through the lower vertical axis (ANHIP106) which is slightly bigger – more open during successful attempts (successful - 28deg; unsuccessful - 26deg). All this indicates that, during successful attempts, Phase II is achieved by an initial slower movement of the supported pendulum backward until the moment of leaving the equilibrium position. This helps control the beginning of the downhill backward from support to the inverted pike hang. During the loss of the support surface, during successful attempts, the supported pendulum (arms and shoulders) reaches a higher velocity, which is further reflected on the bcg velocity in this part of the movement. During successful attempts the inverted pike hang (when the shoulder point is equal to the lower vertical axis) is reached by a more open angle of the hip joint, as an important precondition for the successful realization of the next phase.

The successful performance of the basket to handstand can be predicted based on five kinematic parameters in movement phase III: bcg velocity in the anti-gravitational phase (VBCG122, VBCG136) which is, of course, higher during successful attempts (successful – 3.3 m/s; unsuccessful – 3.1m/s), the shoulder joint angle (ANSHO136) which is bigger during successful attempts (successful – 64deg; unsuccessful – 60deg) and the hip joint angle (ANHIP136) which is also bigger during successful attempts (successful - 155deg; unsuccessful – 139deg) and the size of the angular velocity of anteflexion in the shoulder joint (AVSHO136) which is significantly bigger during successful attempts (successful – 75deg/s; unsuccessful – 30deg/s). The above stated shows that the effects in phase I, II and at the beginning of phase III enabled higher bcg velocity in the anti-gravitational phase during successful attempts. Additionally, a better position of body parts during successful attempts was noted, which was shown by a more open angle of the shoulder and hip joints. This facilitated the regular bcg trajectory during successful attempts, which was more directed at the y axis than to the x axis. Maintaining higher bcg velocity during the anti-gravitational phase was enabled by higher flexion in the shoulder joint. All these facts allowed one to achieve a bigger bcg and foot tip height, as well as a more open angle of the shoulder joint during re-grasping (Figure 3), i.e. achieving a better position which is closer to the handstand during successful attempts.

CONCLUSION

The obtained results gave sufficient feedback which enabled the contestant in question to correct periodical mistakes during the basket to handstand, thus significantly improving the success of his performance on the parallel bars. The procedure of analyzing the performance technique could, in general, be applied to other elements in sports gymnastics, as well as to elements of other conventional-aesthetic sports and sports where the performance technique has an important influence on achieving top results.

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PREDIKCIJA USPEŠNOSTI KOVRTLJAJA DO STAVA U UPORU NA RAZBOJU BAZIRANA NA KINEMATIČKIM PARAMETRIMA – STUDIJA SLUČAJA

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Cilj ovog istraživanja bio je da se utvrdi koji kinematički parametri imaju najveći uticaj na uspeh u izvođenju kovrtljaja do stava u uporu na razboju. Uzorak istraživanja činila su petnaest pokušaja analiziranog elementa izvdena bez greške i petnaest pokušaja izvedena sa srednjom ili velikom greškom u izvođenju. Svi pokušaji su realizovani od strane evropskog i svetskog šampiona na paralelnom razboju, a uspšnost u izvođenju pokušaja procenjivala su trojica međunarodnih sudija muške sportske gimnastike. Dobijeni rezultati su pokazali da se uspešnost u izvođenju analiziranog elementa može predvideti na osnovu ugaone brzine retrofleksora u zglobu ramena, brzine centra ramenog zgloba i veličine ugla u ramenom zglobu u prvoj fazi, a zatim na osnovu brzine težišta tela (BCG), brzine tačka ramena i veličine ugla u zglobu kuka u drugoj fazi i brzine BCG, veličine ugla u ramenom zglobu i zglobu kuka, kao i ugaone brzine anteflekion u ramenom zglobu u trećoj fazi. Istraživanje može poslužiti kao model koji se može primeniti na sve sportove u kojima tehnika izvođenja ima važan uticaj na konačan rezultat.

Ključne reči: *sportska gimnastika, tehnika, kinematička analiza, predikcija*