OPTIMAL KINEMATIC CHARACTERISTICS OF THE UNEVEN BARS DISMOUNTS – A CASE STUDY

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Abstract. The research aimed to investigate the optimal kinematic characteristics of uneven bars dismounts. This scientific approach led to the organization of a case study. The research involved 5 junior gymnasts aged 13-15 years, members of the Romanian national junior team in Deva training center. Research methods used: analysis of the literature; observation method; computerized video method; method of movement postural orientation; statistical and mathematical method using the Chi-Square - nonparametric Kruskal-Wallis Test and Parametric Multiple Comparisons Tukey-Kramer Test. The research results revealed the angular characteristics of body segments in each technical key element consistent with the composition deductions and apparatus-specific deductions. Identification of key elements of the dismount technique based on individual data and the synchronization of spatiotemporal characteristics highlighted differences in segment trajectory and range of motion. The optimal kinematic characteristics of the double back salto dismount of uneven bars show the rotational motion with and without support. The use of computerized video analysis for the biomechanical study of uneven bars dismount contributed to a deeper knowledge of the technical key elements. Highlighting the optimal kinematic characteristics of the studied parameters and indicators helped to develop the linear and branching algorithmic scheme required to improve the technique of uneven bars dismounts.

Keywords: spatiotemporal characteristics, angular velocity, computerized video method, algorithmic learning.

Introduction

Gymnastics continues to grow in popularity and develop in accordance with the trends of performance sports and its specific features. Modern artistic gymnastics has evolved along several years by highlighting the main influences on the gradual increase of skill difficulty (Arkaev & Suchilin, 2004).

Women’s artistic gymnastics (WAG) is the most popular discipline in the gymnastics world. It debuted at the 1928 Olympics. To practice this sport, the gymnast has to master proper muscular strength and flexibility. WAG events include vault, uneven bars, balance beam and floor exercises (Sweeney, 2020). One of the 4 competition apparatus, the uneven bars, improved its construction; the bars became round and thinner, the distance between bars increased, the anchor system was improved; all these contributed to the evolution of the technical execution of elements. The main directions of development are: derivation, composition, concentration and borrowing (Grosu, 2004).

According to the Code of Points (FIG, 2017), the exercise on uneven bars must meet 4 composition requirements; it consists of maximum 8 elements of the highest difficulty including the dismount, which is scored at the difficulty value (DV). The content of the
elements will be divided into 6 structural groups: mounts, casts and clear hip circles, giant circles, Stalder circles, pike circles, dismounts.

As mentioned above, the dismount is no longer a mandatory requirement but is accounted for at DV and contributes to the increase of the final score. In this regard, great attention should be paid to the use of modern learning technologies, as this depends on how the exercise is completed and the final impression of the judges (Readhead, 2011).

Gymnastics involves a lot of skills with unique technical requirements. These skills load the body in a variety of ways. Biomechanics studies the physics or engineering that underlies the movement. The biomechanics of sport is a relatively young scientific discipline due to the appearance of computers and high-speed cinematography (Gavojdea, 2015; Prassas, Kwon, & Sands, 2006).

The main scientific studies focused on the biomechanical analysis of the following elements: giant circles, flight elements and dismounts with various difficulties. Topical biomechanical studies refer to important issues like the transfer of the indicators of technical elements such as giant circles (Hiley & Yeadon, 2007) and clear hip circle to handstand (Petkovic et al., 2018), executed on high bar and uneven bars (Arampatzis & Brüggemann, 1999); research on the execution technique of the basic routines; assessment of the male and female anthropometric indicators related to the results of ranges of motion and velocity, momentum and angular velocity (Hiley & Yeadon, 2003; Sheets & Hubbard, 2009); identification and quantification of injury mechanisms and risk factors (Bradshaw & Hume, 2012).

However, the concerns and guidelines in the biomechanical research on uneven bars are of particular interest for finding the most important information needed to improve the technique (Crețu, 2004).

The research purpose is to investigate the optimal kinematic characteristics of the dismount performance on uneven bars.

The research question - Does the use of the computerized video analysis necessary for the biomechanical study of the uneven bars dismount contributes to the more thorough knowledge of the technique key elements?

Highlighting the optimal kinematic characteristics of the studied parameters and indicators will help to develop the linear and branching algorithmic scheme required to improve the technique of uneven bars dismounts.

**Methodology**

**Participants**

A number of 5 female gymnasts aged 13 to 15 years, members of the Romanian national team from the training center of Deva, participated in this study. The selection of gymnasts for the research was made on the criterion of their participation in the Junior National Gymnastics Championships, Onești 2017.
Procedure

The study was conducted in conformity with the Declaration of Helsinki on the research involving human subjects and with the Ethics Commission of the Ecological University of Bucharest.

The following research methods were used to achieve this study: analysis of the literature; observation method with direct participation and video recordings taken from YouTube (perpendicular to the plane of movement); computerized video method using the specialized programs:
- Pinnacle studio for converting video capture from mp4 into avi format, 30 frames/sec.
- Kinovea for measuring the angular characteristics of body segments in the technique key elements of uneven bars dismounts.
- Physics toolkit for measuring the kinematic characteristics of the trajectory of body segments (foot, hip joint – CoM, shoulder and wrist) and angular velocity (rad/s).

The movement postural orientation method (Boloban, 2013 and supplemented by Potop, 2015) was used for the analysis of the kinematic characteristics of the double back salto piked dismount. This method allows the identification of key elements in the phasic structure of the sports technique of gymnastics exercises. The conceptual significance of this method consists in the fact that each body posture must positively influence the biomechanical characteristics of the next posture; thus, the execution of supplementary movements and the accumulation of technical errors are not allowed in the process of demonstrating a combination or the whole exercise.

Due to the technical structure of the double back salto piked dismount off the uneven bars, the biomechanical analysis was divided into two parts (Figure 1):

a) Supported rotational motion (MRS) – back giant circle, preparatory phase:
- sub-phase 1 (SPh1), moment of crossing over the low bar;
- sub-phase 2, (SPh2), body launching posture (LP), moment before releasing the high bar.

b) Rotational motion without support (MRNS), basic phase, multiplication of body posture piked (MP1) – beginning of the flight phase, MP2 - maximum height of the center of mass of the body (CoM), MP3 – end of the flight phase and final phase – concluding body posture (CP) – landing.

![Figure 1. Phasic structure of the technique of double back salto piked dismount off the uneven bars (FIG, 2017)](image-url)
In order to perform the biomechanical analysis of the dismount, the body segments (foot, CoM and shoulders) were separately measured in MRS 3 – with the bar as axis of rotation; in MRNS, 3 segments (foot, shoulders and wrist) were measured related to CoM (axis of rotation).

Main anthropometric parameters used (n = 5, mean ± SD): height (m) – 147.28 ± 4.81 m; standing reach (m) – 192.36 ± 3.50 m and weight – 39.45 ± 3.84 kg.

Necessary indicators for the biomechanical analysis:

a) MRS: RI – rotational inertia (kg·m²), RM – radius of motion (m): foot, hip joint (CoM) and shoulders.

b) MRNS: RI (kg·m²), RM (m): foot, shoulders and arms.

The key elements of the technique (Figure 1) were identified in each gymnast, highlighting the spatiotemporal characteristics and angular velocity. The aim was to synchronize and centralize the data for each body segment and the technique key elements in both parts of the exercise.

The algorithmic learning method, namely the linear and branching algorithmic scheme (Potop, 2015), was used to improve the dismount execution technique. Three main groups of exercises were used within the methodological structure: aiding exercises; supplementary exercises with aiding – preparatory character; exercises to control and correct learning.

The statistical analysis was performed using the KyPlot program and Microsoft Excel. The data were calculated for each gymnast separately, showing the statistical indicators: mean, SEM – standard error of the mean, SD – standard deviation, Cv% – coefficient of variation. The Chi-Square – nonparametric Kruskal-Wallis Test (Dwivedi, Mallawaarachchi, & Alvarado, 2017) was used to highlight the significance of the performance achieved in the uneven bars event.

The average of the body segments in each part of the exercise was calculated using MS Excel. To show the influence of the spatiotemporal characteristics and optimal segmental angular velocity, the Parametric Multiple Comparisons Tukey-Kramer Test was used: Pairwise Comparisons for One-Way Layout Design (McHugh, 2011). In MRS, the average of 9 indicators (A1-9) was used: foot (X,Y), CoM (X,Y), shoulders (X,Y), foot (rad/s), CoM (rad/s) and shoulders (rad/s); as for MRNS – the average of 11 indicators (A1-11): CoM (X,Y), foot (X,Y), shoulders (X,Y), wrist (X,Y), foot (rad/s), shoulders (rad/s) and wrist (rad/s).

**Results**

Table 1 shows the results of the angular characteristics of body segments during the competitive execution of double back salto piked dismount off the uneven bars by junior gymnasts aged 13 to 15 years within the Team and Individual National Championships of Juniors II Level 4, Onesti, 03-04.06.2017.
Table 1. Angular characteristics of body segments during the execution of the double back salto piked dismount off the uneven bars by junior gymnasts

| Name | Hip circle | Clear hip circle |
|------|------------|------------------|
|      | Preparatory phase | Basic phase | Concluding phase |
|      | SPh1, degrees | SPh2 – CP, degrees | MP3, degree | CP, degree |
| M.L. | 172 | 155 | 132 | 97 | 106 |
| S.S. | 135 | 170 | 143 | 108 | 83 |
| P.L. | 150 | 144 | 123 | 111 | 105 |
| B.V. | 139 | 176 | 156 | 99 | 108 |
| P.M. | 133 | 183 | 149 | 97 | 78 |

Table 2 presents the results of the biomechanical indicators needed for the technical analysis of the uneven bars double back salto piked dismount executed during the Team and Individual National Championships of Juniors II Level 4, Onesti, 03-04.06.2017.

Table 2. Biomechanical indicators needed for the technical analysis of the double salto backward piked dismount off the uneven bars executed by junior gymnasts

| Name | R.I. (kg·m²) | Phase of hip circle | R.I. (kg·m²) | Phase of clear hip circle |
|------|--------------|---------------------|--------------|--------------------------|
|      | Foot | CoM | Shoulder | Foot | shoulder | wrist |
| M.L. | 116.02 | 1.366 | 0.896 | 0.565 | 14.35 | 0.567 | 0.288 | 0.362 |
| S.S. | 144.49 | 1.525 | 0.927 | 0.489 | 17.88 | 0.713 | 0.368 | 0.374 |
| P.L. | 138.26 | 1.407 | 0.981 | 0.601 | 17.28 | 0.623 | 0.383 | 0.405 |
| B.V. | 119.94 | 1.439 | 0.996 | 0.657 | 14.83 | 0.634 | 0.374 | 0.358 |
| P.M. | 130.74 | 1.601 | 1.029 | 0.587 | 16.51 | 0.728 | 0.361 | 0.450 |
| mean | 129.89 | 1.467 | 0.966 | 0.579 | 16.17 | 0.653 | 0.355 | 0.389 |
| SEM | 5.36 | 0.04 | 0.02 | 0.03 | 0.68 | 0.03 | 0.02 | 0.02 |
| SD | 11.99 | 0.09 | 0.05 | 0.06 | 1.53 | 0.07 | 0.04 | 0.04 |
| Cv% | 9.23 | 6.45 | 5.56 | 10.53 | 9.47 | 10.24 | 10.77 | 9.84 |

Note: SEM – standard error mean; S.D. – standard deviation; Cv – coefficient of variation; RI – rotational inertia; CoM – Center of mass of the body (hip joint).
The statistical and mathematical results at MRS revealed RI with an average of 129.89 kg·m²; foot RM with an average of 1.467 m, CoM – 0.966 m, shoulders – 0.579 m; for MRNS, RI had an average of 16.17 kg·m²; segmental RM of the relation CoM with the foot – an average of 0.653 m, with the shoulders – 0.355 m, and with the arms – 0.389 m.

Figure 1. Averages values of body segment trajectories during the execution of double back salto piked dismount off the uneven bars - (a) MRS; (b) MRNS

Figure 1 (a and b) highlights the optimal spatiotemporal characteristics of the body segments during the execution of double back salto piked dismount, regarding MRS in preparatory phase (SPh1 and SPh2) of the segments: foot, CoM and shoulders; in MRNS with basic phase (MP1, 2, 3) and conclusion (CP) – landing. Data calculations show an average duration of the whole dismount of 1.117 sec. The variation in value of the angular velocity of segments influenced the differences of temporal moments in each key element of the technique, exemplified by the size of intervals (in SPh1 of 0.267-0.367 sec and in SPh2 of 0.533-0.667 sec). There were also discrepancies between segments at CP – landing because of the height (MP2x,y = 0.83; 0.56 m) and length of the dismount flight (CPx = 1.33 m).

Tables 3 and 4 show the results of the multiple comparative analysis of the average between the spatiotemporal indicators and the angular velocity of the segments in MRS and MRNS. The results of the analysis highlighted significant differences at p < 0.001 between the indicators A1-6 and A7-9 in MRS and between the indicators A1-8 and A9-11. This means that there are no significant relationships between the indicators of the same characteristic; instead, the combination of these relationships has a significant influence.

Table 3. Multiple parametric comparative analysis of indicator averages at dismount in MRS

| Ind. | A1  | A2  | A3  | A4  | A5  | A6  | A7  | A8  | A9  |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| MRS  | Foot(Xm) | Foot(Ym) | CoM(Xm) | CoM(Ym) | Should(Xm) | Should(Ym) | Foot(rad/s) | CoM(rad/s) | Should(rad/s) |
| A1   | 0.415 | 0.207 | 0.465 | 0.314 | 0.461 | 14.46*** | 12.64*** | 12.13*** |
| A2   | -0.208 | 0.050 | -0.100 | 0.045 | 14.05*** | 12.23*** | 11.72*** |
| A3   | 0.258 | 0.107 | 0.253 | 14.25*** | 12.43*** | 11.93*** |
| A4   | -0.150 | -0.004 | 14.00*** | 12.18*** | 11.67*** |
| A5   | 0.146 | 14.15*** | 12.32*** | 11.82*** |
| A6   | 14.01*** | 12.18*** | 11.67*** |
| A7   | 1.80 | 2.29 | -0.49 |
| A8   | 49   | 82   | 93   |
| A9   | 129  | 75   | 13   |
Table 4. *Multiple parametric comparative analysis of indicator averages at dismount in MRNS*

| Ind. | A1 | A2 | A3 | A4 | A5 | A6 | A7 | A8 | A9 | A10 | A11 |
|------|----|----|----|----|----|----|----|----|----|-----|-----|
| MRNS | CoM (Xm) | CoM (Ym) | Foot (Xm) | Foot (Ym) | Should (Xm) | Should (Ym) | Wrist (Xm) | Wrist (Ym) | Foot (rad/s) | Shou Ld (rad/s) | Wrist (rad/s) |
| A1   | -0.78 | -0.04 | -0.82 | 0.02 | -0.79 | -0.01 | -0.80 | 10.26*** | 10.84*** | 9.50*** |
| A2   | 0.73  | -0.04 | 0.80  | -0.01 | 0.77  | -0.02 | 11.04*** | 11.63*** | 10.28*** |
| A3   | -0.77 | -0.74 | 0.07  | -0.41 | 0.04  | -0.75 | 10.30*** | 10.89*** | 9.55*** |
| A4   | 0.84  | 0.03  | 0.81  | 0.02  | 11.08*** | 11.67*** | 10.32*** |
| A5   | -0.80 | -0.03 | -0.82 | 10.23*** | 10.83*** | 9.48*** |
| A6   | 0.78  | -0.02 | 11.05*** | 11.63*** | 10.28*** |
| A7   | -0.79 | -0.79 | 10.27*** | 10.86*** | 9.51*** |
| A8   | 11.06*** | 11.65*** | 10.30*** |
| A9   | 0.58  | -0.76 | |
| A10  | -1.34 | |
| A11  | |

Note: Parametric Multiple Comparisons Tukey-Kramer Test: Pairwise Comparisons for One-Way Layout Design; *** - p < 0.001

Table 5 shows the results of the performances obtained on uneven bars during the Team and Individual National Championships of Juniors, Onesti, 03-04.06.2017. Individual performance (difficulty, execution and final score), the value of the statistical indicators and also the statistical significance at p < 0.05 were presented.

Table 5. *Results of individual performance obtained in the uneven bars event*

| Full name | Difficulty, points | Execution, points | Final score, points |
|-----------|-------------------|------------------|---------------------|
| M.L.      | 3.500             | 8.633            | 12.133              |
| S.S.      | 4.200             | 7.933            | 12.133              |
| P.L.      | 4.000             | 7.900            | 11.900              |
| B.V.      | 2.800             | 8.733            | 11.533              |
| P.M.      | 3.000             | 8.100            | 11.100              |
| mean      | 3.500             | 8.259            | 11.759              |
| SEM       | 0.27              | 0.17             | 0.19                |
| SD        | 0.61              | 0.39             | 0.44                |
| Cv %      | 17.37             | 4.78             | 3.76                |
| Chi       | 12.52             |                  |                     |
| P-Value   | 0.001             |                  |                     |

Note: SEM – standard error mean; SD – standard deviation; Cv – coefficient of variation; Chi-Square - nonparametric Kruskal-Wallis Test

Following this research, the authors proposed a linear and branching algorithmic scheme for the improvement of the double salto piked dismount (Figure 2).
Figure 2. Linear and branching algorithmic scheme for learning the back double salto piked dismount off the uneven bars

Note: S – purpose of learning: learning of the uneven bars dismounts – back double salto tucked, piked and tucked with 360° twist; SP – pedagogic tasks: 1) Learning of the crossing over the low bar technique in the first sub-phase (SPh1) of the preparatory movement and completion of the back giant circle in SPh2 as body launching posture (PL). 2) Learning to conduct body posture multiplication (MP) tucked, piked and tucked with 360° twist in the basic movement phase. 3) Learning of standstill landings. EP1- EP4 – sequences of learning material (aiding exercises): EP1-2 – execution of body launching posture (PL); EP3 – exercises to develop skills for MP in tucked, piked and hanging layout position and flight. EP4 – exercises to develop skills for standstill landing. EP1.1- EP4.1 – additional sequences with aiding-preparatory character: EP1.1 – 2.1 – exercises to develop the movement of arms and whole body during efficient performance of exercises in supported and hanging position. EP3.1 – exercises for development and improvement of the body orientation in space (trampoline and foam pit - trampoline complex). EP3.2 – exercises to develop skills for execution of the tucked, piked and layout salto and double salto tucked on the floor. EP4.1 – exercises to develop the muscular strength of legs and back; exercises to develop skills for mechanical taking over of the contact with the floor at landing (damping). C1- C4 – control, correction of the learning process: C1 – 2 – from handstand, back giant circle, execution of bar release in optimal position; C3 – assessment of execution technique of MP in the double back salto tucked; C4 – performance of back double salto tucked from the table for deep jumping with standstill landing on mats; execution of double salto from trampoline with standstill landing on mats. RÎ – result of learning: performing double back salto dismounts (tucked, piked and tucked with 360° twist) with a score not lower than 9.0 points.

Discussion

The research purpose was to investigate the optimal kinematic characteristics in order to improve the uneven bars dismounts.

This scientific approach entailed the organization of a case study with the participation of 5 junior gymnasts aged 13-15 years, members of the Romanian junior national team, within the Olympic Training Center of Deva. The biomechanical study was conducted in competitive conditions during the National Gymnastics Championships of Juniors, Onesti, 2017.

The computerized video method was used to perform the biomechanical analysis of the uneven bars double salto dismount in competition conditions. The angular characteristics of body segments in the technique key elements were measured using Kinovea program (Table 1); the kinematic characteristics were evaluated with the help of Physics toolkit program (Table 2). The biomechanical indicators necessary for the technical analysis, the spatiotemporal indicators (segmental trajectories) and the angular velocity were highlighted.
The optimal spatiotemporal characteristics of body segments during the execution of the double back salto piked highlight the supported rotational motion (MRS) in the preparatory phase (SPh1 and SPh2) of the following segments: foot, CoM and shoulders and the rotational motion without support (MRNS) with basic phase (MP1,2,3) and concluding phase (CP) – landing (fig. 1 a and b).

The averages of the studied indicators were calculated on the basis of individual data; the comparative multiple analysis between indicators was made using the Parametric Multiple Comparisons Tukey-Kramer Test (McHugh, 2011). The analysis results revealed insignificant differences of the spatiotemporal indicators \((p > 0.05)\) and angular velocity \((p > 0.05)\); the comparison between indicators showed significant differences at \(p < 0.001\) (Tables 3 and 4).

Our concerns on the biomechanical study focused on the biomechanical characteristics of the uneven bars dismounts (Potop, 2014; Potop et al., 2014) and on the biomechanical characteristics of the transfer in the rotational movements on uneven bars (Potop, Grigore, Timnea, & Ulareanu, 2014). A mathematical modelling of the biomechanical characteristics of the dismounts off uneven bars was made (Potop, Mihaila, & Urichianu, 2015). The comparative analysis of the biomechanical characteristics of sports technique used in dismounts and the performances achieved by junior gymnasts in uneven bars events were also approached (Potop, Timnea, & Stanescu, 2017). The influence of the physical training on the technical execution of the uneven bars dismounts was analyzed as well (Potop & Cretu, 2018).

The analysis of the literature highlights the biomechanical studies that also reveal didactic implications. For the improvement of the back giant circle and dismount techniques, there were used some means selected on biomechanical criteria, individualized as needed, for solving certain tasks meant to improve the execution in parts, connections, phases and postures (Creţu, 2004; Hunter & Torgan, 1983). The approach of the comparative biomechanical study of the front giant circle in the dismount off the uneven bars seems to be similar to the” traditional” technique used by some male gymnasts (Hiley & Yeadon, 2005).

It was also investigated the optimal technique in the presence of motor system noise (Hiley & Yeadon, 2016).

The assessment of the technical training level on uneven bars was made by comparing the results of optimal kinematic characteristics of the double salto piked dismounts (Tables 3 and 4) and the score obtained in competition (Table 5). Based on these observations, a linear and branching algorithmic scheme was developed to improve the key elements of the dismount technique and get a better score for the execution of the competition exercise (Potop, 2015).

Conclusion

The research results highlighted the angular characteristics of body segments in the technique key element in accordance with the deductions specific to the apparatus and the composition deductions.

The identification of the dismount key elements based on individual data and the synchronization of the spatiotemporal characteristics revealed differences in segment trajectory and range of motion.
The optimal kinematic characteristics of the double salto dismount off the uneven bars highlights the MRS with the preparatory phase, the MRNS with the basic phase (MP) and the concluding phase (CP) – landing.

The use of the computerized video analysis necessary for the biomechanical study of uneven bars dismounts technique contributed to a more thorough knowledge of the technique key elements.

Highlighting the optimal kinematic characteristics of the studied parameters and indicators helped to create the linear and branching algorithmic scheme needed to improve the technique of the uneven bars dismounts.

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