KINEMATIC ANALYSIS OF THE NEW ELEMENT "DIMIC" AND ITS COMPARISION WITH "BILOZERCHEV" ON PARALLEL BARS

Edvard Kolar[1], Sebastijan Piletič[2], Klemen Bedenik[2], Mitija Samardžija Pavletič[2], Stanko Štuhec[3], Saša Veličković[4]

[1]University of Primorska, Science and Research Centre, Institute of Kinesiology Research, Koper, Slovenia
[2]Gymnastics Federation of Slovenia
[3]University of Ljubljana, Faculty of Sport, Ljubljana, Slovenia
[4]University of Niš, Faculty of Sport and Physical Education, Niš, Serbia

Original article

Abstract

Development and recognition of new gymnastics element is subjected to the evaluation of difficulty and structural complexity of the skill. The authority over the procedure lies with the Technical Committee of International Gymnastics Federation (FIG TC) and thus the classification of an element is a result of the subjective perception of its members. The present article pursued two goals. First, a method of biomechanical modelling was used to present a new gymnastics element "Dimic" on parallel bars. Second, as the element "Dimic" was evaluated with the same difficulty and placed in an identical position as "Bilozerchev" element in the Code of Points tables, the accuracy of the evaluation was tested by comparing kinematical characteristics of both elements. Measured subject was a gymnast AD, who for the purpose of the study performed both elements. Kinematic analysis was performed with the help of APAS 3-D video motion analysis system, using a model with 17 points and 15 segments. A comparison of kinematic characteristics (movement of body centre of gravity and the supporting left hand, the amount of rotation around the longitudinal axis) revealed significant differences in a non-support phase of elements both in structural characteristics and the difficulty of the execution of the skills. It can be concluded that the placement of the "Dimic" skill in the Code of Points seems incorrect. A method used in the study could in future be used in order to more adequately place new skills into the Code of Points.

Keywords: *new skills, evaluation, Code of Points.*

INTRODUCTION

Based on the structural complexity of movements (Matveev, 1977) in individual sports disciplines, gymnastics has been categorised into a group of conventional sports, which are characterized with aesthetic and physically determined acyclic sets of structures that can be carried out either in standard or varied external conditions. Conventional character of artistic gymnastics defines the process of managing sportsmen in gymnastics. Conventionality of sports discipline implies that all motion/movements must be performed in the context of a particular motoric model (prescribed by the experts - convention), which could be called the *ideal* *model of movement* (IMM). IMM is determined with the biomechanical model of movement and is prescribed in the regulations (Code of Points) for the assessment by the International Gymnastics Federation (FIG). Evaluation of the athletes in conventional sports is carried out by judges evaluating the performance of motion content, which athletes demonstrate in competitions. The criterion of evaluation is based on the comparison between the IMM and actually performed movement by each gymnast. Therefore, the number and the complexity of the elements, which the gymnast masters and is able to successfully (in accordance with regulations) perform at the competitions, primarily define success in conventional sports (Kolar, Samardžija-Pavletič, & Veličković, 2015).

Elements in the Code of Points (FIG, 2013) are assigned different difficulty according to the complexity of their movement. In sports training theory, term motor structure technique (element) represents a certain form of motion, which is standardized and identified by name. Motor technique and IMM in the performance of gymnastics elements are determined with the biomechanical model of movement and its kinematic and dynamic characteristics (Kolar, Piletič, & Veličković, 2005, p. 12-13). Biomechanical modelling is used to reveal relevant physical - biomechanical model for the selected element or movement in order to describe the movement and define the technique of a particular element with physical values. The physical description of motion is required in arbitrarily selected data in order to predict the movement with numerical values of its quantity, such as velocity, acceleration, force, etc.

Biomechanical models of the elements can be used for the different purposes. When used only for the sake of analysis and description of motion, biomechanical model needs to be properly interpreted and described with calculated kinematic and dynamic parameters (Davis, 2005; Heng, 2007; Linge, Hallingstad, & Solberg, 2006; Manoni, De Leva, Carvelli, & Mallozzi, 1992a; 1992b; Marinšek, Kolar, Piletič, & Kugovnik, 2006; Prassas, 1994; Prassas & Ariel, 2005; Tsuchiya, Murata, & Fukunaga, 2004; Veličković et al., 2011). Further use of such biomechanical model is in the planning of methodical procedures or in the planning of physical preparation for analysed movement (Čuk, 1996; Veličković, 2005; Veličković et. al., 2013). In the evaluation of methodical procedures, it is necessary to adequately explain each methodical step, its adequacy and advantages over other steps, and the reasons for skipping individual methodical steps and shortening the methodical process (Kolar, Andlovic-Kolar, & Štuhec, 2002). Identification of errors during movements or detection of inconsistency in the performance of the elements requires a large number of repetitions of an element (Gervais & Dunn, 2003; Hiley, Wangler, & Predescu, 2009; Kolar, Piletič, Kugovnik, Andlovic-Kolar, & Štuhec, 2005; Prassas, Ostarelo, & Inoraj, 2004; Veličković, 2005). Introduction of new elements requires mathematical modelling of already accomplished movements, when a different body position is foreseen in the movement performance (e.g. straight instead of tucked position) or when rotation around the longitudinal or transverse axes is added to already accomplished movements (Čuk, 1996; Čuk, Atiković, & Tabaković, 2009).

Biomechanical model of skills can also be used to compare skills and find differences or similarities in the technique and complexity of elements (Čuk, 1995; Manoni, De Leva, Carvelli, & Mallozzi, 1992b; Veličković et. al., 2005). Such comparisons should also be used when setting a difficulty of skills and their placement in the FIG Code of Points, particularly in cases of new skills that have previously not been included in the tables. The study aims to fulfil two goals. The first is a presentation of a new gymnastics element “Dimic” on parallel bars. The second is to use kinematic characteristics of the skill for testing the correctness of the decision made by the FIG Men’s Technical Committee (MTC) about the difficulty of the skill and its placement in the Code of Points.

Element "Dimic" on parallel bars has been performed for the first time on September 2 2011 at the World Cup series competition in Ghent (qualifications). Evaluation of an element from the FIG MTC was following (FIG, 2013):

- element was placed in a *group I of elements on parallel bars*,
- element was categorised as a *D difficulty element*,
- element was placed in *box I.10 together with Bilozerchev element*.

As "Dimic" and "Bilozerchev" were both placed in box I.10 in the Code of Points (see Figure 1), consequently gymnasts are not allowed to perform both elements in the routine. Nevertheless, the following comparison of kinematical parameters will reveal that the elements are different in their movement structure.

METHODS

The sample is represented by A.D (age 27 years; body height 1.72 m; body mass 64 kg) a Slovenian men's artistic gymnastics national team member, a multiple medal winner on parallel bars at the World Cup competitions. Measured participant has performed both elements in competitive exercise (Bilozerchev between 2004 until 2011; Dimic from 2011 onwards).

Measurements and data analysis were carried out in standard method, as prescribed by 3D Ariel Performance Analysis System (APAS). As part of the kinematic analysis, digitization of the 15-segment model (Dempster, 1955) of competitor was conducted. Measurements were performed on 07/09/2011 in Ljubljana (SLO). Measured participant performed both elements in training. Both elements were recorded with the help of two synchronized DVCAM - Sony - SR - 300 PK cameras, with a 50Hz framerate. Before recording, and for precise space calibration, two reference frames were videotaped ($1m^3$), which were positioned in the middle of the parallel bars. Centre point of the coordination system was at the centre between the bars (Figure 5). For research purposes, successful (without technical errors) execution of each element was evaluated by three international judges and selected for further analysis.

For the presentation of new gymnastic skill "Dimic", a model by Smolevskij (1992) was used to present a theoretical biomechanical model of the element.

Sample of variables is represented with selected kinematical parameters (trajectories and angles), describing the most significant differences in the movement of both elements. For the purpose of the research, following parameters were calculated:

- path (trajectory) of the body centre gravity in z-axis (D_BCG_z_Dimic and D_BCG_z_Bilozerchev);
- path (trajectory) of the supporting arm in z-axis (D_L_wrist_z_Dimic and D_L_wrist_Bilozerchev);
- rotation of the hip joint around longitudinal axis (ROT_hips_Dimic and ROT_hips_Bilozerchev);
- rotation of the shoulder joint around longitudinal axis (ROT_shoulders_Dimic and ROT_shoulders_Bilozerchev)

Finally, velocity in horizontal (V_BCG_x_Dimic) and vertical (V_BCG_y_Dimic) axes in the element "Dimic" was calculated in order to appropriately present the new gymnastics skill.

RESULTS

Element "***Dimic" on parallel bars*** is an element from group I, consisting of the *elements performed in or through support on both bars*. Movement in element "Dimic" can be described in two ways (Figure 2):

- as a "stutkzkehr" forward with 1/4 turn to handstand sideways on 1 rail (Bilozerchev with 1/2 turn), or
- as a ¾ turn in forward swing in support with hop to opposite bar into handstand on one bar, facing out.

- According to the position of the gymnast in relation to the apparatus during the performance of movement (Smolevskij, 1992), “Dimic” skill can be divided into:
- support part (Figure 2; positions 1 to 7),
- non-support part (Figure 2; position 8) and
- support part on both hands on one rail (Figure 2; positions 9 and 10).

Support part of the skill is represented with a movement from the handstand to the high forward swing (see Figure 2; positions 1 – 7). Movement in this part of the skill can be approximated as a suppressed motion of a two-segment stiff body (Opavsky, 1971). In execution of the movement, the centre of gravity of a subsystem forearm-upper arm lies above the supporting area. Thus, the entire system is supported above the point of contact (grip) with the apparatus and acts as a supported pendulum. The centre of a second subsystem head-torso-legs acts as a suspended pendulum and lies below the shoulder axis, which represents a meeting point of both subsystems. A supporting area for the entire system is relatively small and as a result maintaining of balance in swing is difficult. In order to achieve swinging with large amplitudes, it is imperative that both mentioned subsystems are simultaneously coordinated in opposite directions (Marinšek, Kolar, Piletič, & Kugovnik, 2006, p. 40). This leads to oscillation of the body centre of gravity (BCG) as close as possible to the vertical line, which runs through the supporting area. Nevertheless, the execution of more difficult skills in support on parallel bars require oscillation of the BCG in forward and backward direction that is larger than allowed by the supporting area. Such deviations away from the supporting area allow the gymnast a better exploitation of swing that is required for the execution of the succeeding skill (Marinšek, Kolar, Piletič, & Kugovnik, 2006, p. 40). This is achieved with an intermuscular coordination of the entire system and the strength of arms and wrists, which enables a strong grip of the bars and results in a dynamic balance of the entire system. Dynamic balance is a term, which describes keeping the BCG above the supporting area whilst the entire system (i.e., gymnast) is in motion (Kolar et al., 2005). The aim of dynamic balance is to achieve positions enabling most optimal execution of movement with only small adjustments. According to the criterion of the direction of force acting (Smolevskij, 1992), the supporting part of the skill can be divided into an accumulation phase (see Figure 2; positions 1 – 5) and work phase (see Figure 2; positions 6 – 7).

Accumulation phase is represented with a downward movement from the position of handstand to the position of lower vertical (see Figure 3; from t=0.0s to t=0.52s). The characteristic of the accumulation phase is that the body moves in the same direction as the gravity acts, resulting in the positive acceleration of the body (+α). In ***work phase*** the gymnast moves from lower vertical into forward upward swing, in the opposite direction to the gravity acting, which decelerates the body (-α). According to this, gymnast should acquire the highest velocity at the point of transition from accumulation to the work phase. However, some authors have found that the movement of the BCG when swinging on parallel bars is similar to the yo-yo movement as seen when looking at the trajectory of BCG, which describes the U-path and not the circular path (Kolar, Andlovic-Kolar, & Štuhec, 2002; Mannoni et al. 1992a). The phenomenon could be explained with the elasticity of the parallel bars, acting on the gymnast according to the action-reaction principle and the oscillation of the shoulders (supported pendulum motion) (Kolar, Andlovic-Kolar, & Štuhec, 2002; Kolar et al., 2005). In the moment, when gymnast starts to move shoulders backward (when suspended pendulum crosses the horizontal position in the accumulation phase; Figure 2; position 4), BCG starts to move closer to the supporting area (angle in the shoulder joint (ϕ) is getting smaller). As a result, radial force (Fr) increases whilst the tangential component of the force (Ft) decreases, whilst the force of gravity (Fg) is represented with a product of gymnast's mass and the acceleration due to gravity near the surface of Earth (9.8 m/s^2) (see equations 1a and 1b).

(a) $Fr = Fg * \cos\phi$

(b) $Ft = Fg * \sin\phi$

Increase of the radial force component results in the increase of the force acting on the surface (larger part of the body mass is above the supporting area). As the force acting on the parallel bars also increases, the bars bend due to their elasticity (Figure 2; position 5), which results in decreased vertical velocity and increased horizontal velocity of the BCG (see Figure 3; from t=0.33s to t=0.52s). After the body passes the lowest point of the movement (see Figure 3; t=0.52s), gymnasts enters ***work phase*** and executes the movement from the lower vertical to the moment of release with supporting arm (see Figure 3; from t=0.52s to t=0.93s). During this movement, the force acting on the parallel bars continues to increase for a short period (reaction principle) and thus helps the BCG with upward acceleration, transpiring in larger vertical and smaller horizontal velocity of the BCG (see Figure 3; from t=0.52s to t=0.72s) (Marinšek et al., 2006; Marinšek & Kolar, 2007). Gymnasts achieves the highest vertical velocity (see Figure 3: $Vy = 2.96\ m \cdot s^{-1}$; t = 0.68 s) just prior to the release with the take-off arm (in this case right arm) and transition to the one-arm support (i.e., left arm) (see Figure 3: t = 0.72s).

Eccentric push sideways (in Z-axis) with a take-off arm and the leaning on the supporting arm results in the transverse axis of the gymnast moving away from the vector of angular momentum. The direction of the latter allows the body of the gymnast to commence rotation around the longitudinal axis (Yeadon, 1999), which is enabled by beginning the turn in a contact-way (see Figure 2; positions 6). The turn around the longitudinal axis is initiated with the turn of the hips in the direction of the turn (see Figure 4; t=0.66s) and the turn of the shoulders, which first move into the opposite direction (see Figure 4; from t=0.66s to t=0.81s) and then in the same direction as the body (see Figure 4; from t=0.82s). Movement in this part of the skill can be described as the combination of translation and rotation around the longitudinal axis. Gymnast uses accumulated energy in order to execute desired movement on the supporting arm to the point of high forward swing (see Figure 2; position 7), whilst performing the turn with the hips for 117.9°and shoulders for 87.2° around the longitudinal axis (see Figure 4; from t=0.72s to t=0.93s).

Movement on the supporting arm in the work phase ends when the gymnast performs an eccentric take-off from the parallel bars also with the supporting arm (see Figure 2; positions 7). At this time, gymnast begins a ***non-support part*** or ***execution phase*** (see Figure 3 and 4; from t=0.93s to t=1.31s) of the element. The direction of the eccentric take-off with supporting arm in the Z-axis is opposite to the push from the take-off arm in the moment of the transition onto supporting arm. This leads to the body moving in Z-axis into opposite direction to the supporting arm (see Figure 2; positions 7 - 9). The gymnast uses accumulated energy from the support part of the skill in order to execute desired movement in the non-support part of the skill. Linear momentum acquired in the support part of the skill will determine if the gymnast will be able to end the skill in the desired final position, whereas the angular momentum mostly defines whether the gymnast will be able to perform required rotation around the longitudinal axis in the non-support part (execution phase) of the skill. In the execution part of the skill a gymnast performs turn with the hips for 94.6° and with shoulders for 162.1° around the longitudinal axis (see Figure 4; from t=0.93s to t=1.31s). The movement in the execution phase can be described with the Principle of conservation of angular momentum (Prassas, 1999). Angular momentum is a vector product of linear momentum (G) and the lever (r) or the product of angular velocity and the moment of inertia of the body (J), which is equal to the product of the lever squared (r^2) and mass (m) (see equations 2a, b and c):

(a) $\Gamma = G\,r = (mv)r$

(b) $\Gamma = J\omega = (M/\alpha)\omega$

(c) $J = mr^2$

A gymnast can use the work of muscles in order to change the moment of inertia of the system. By reducing or increasing the distance of the take-off arm (with the supporting arm in extended position - see Figure 2; position 8) from the axis of rotation, the gymnast also reduces or increases body moment of inertia and consequently increases or reduces the angular velocity. This enables a gymnast to control angular velocity in the execution of turning around the longitudinal axis in non-support part and precise ending of the execution phase of the skill (Marinšek et al., 2006; Yeadon, 1999).

Non-support part of the skill ends at the moment when a gymnast grabs the opposite rail with the take-off arm, finishing in a ***support part with both hands on one rail*** (see Figure 2; positions 9 and 10). Due to the acting of forces, the support part with both hands on one rail can be called ***amortisation phase*** (see Figure 4; from t=1.31s to t=1.52s), when a gymnast finishes the rotation of the body around the longitudinal axis into support position (see Figure 4; hips for 35.2° and shoulders for 21.1°). Similarly to the work phase, in the amortisation phase gravity acts in the opposite direction to the muscular activity. When a gymnast lands in handstand, the impact of torques of all external forces onto the body of the gymnast has to be equal to the angular momentum in non-support part, allowing the gymnast to finish the skill in still position (Kolar & Piletič, 2005, p. 23).

A comparison of elements "Dimic" and "Bilozerchev" on parallel bars reveals some similarities between the skills. Both elements start in the same position (handstand in support on both bars) and continue their movement in the same direction into forward swing in support. They are both performed on the same supporting arm (left arm).

Both elements end in the same final position (handstand in support sideways on one bar facing out); nevertheless, an important difference in these positions can be noticed. Final position of "Dimic" skill is on the opposite bar from the supporting arm in handstand facing out while the final position of "Bilozerchev" skill is on the same bar as the supporting arm in handstand facing out. Identified difference indicates that the body centre gravity and other body parts in execution phase of the element "Dimic" travel on a longer path in z-axis (deviation from centre of parallel bars – see Figure 6: the difference in the position of the BCG is 0.706m and the difference in the position of the supporting left arm is 0.592m) in comparison to the element "Bilozerchev". During the "Dimic" element – from the beginning of work phase on both hands (t=0.52s) to the end of amortization phase (t=1.52s) – the BCG travelled 0.440m, which compared to the element "Bilozerchev" (travel of the BCG is 0.259m) reveals a difference of 0.181m (69.9%). Similar results have been noticed for the supporting left arm, which from the beginning of work phase on support hand (t=0.72s) to the end of amortization phase (t=1.52s) travelled 0.595m in element "Dimic" and only 0.003m in element "Bilozerchev", showing a difference of 0.592m.

Additionally, important difference between the two elements was revealed in the amount of rotation around the longitudinal body axis (y-axis) in the execution phase of each element. In the element "Dimic", body rotates for approximately ¾ of a turn (see Figure 7, 269.1° hips and 276.3° shoulders) around the longitudinal axis, whereas in the element "Bilozerchev" body rotates only for around ¼ of a turn (Figure 7, 87.6° hips and 88.2° shoulders) around the longitudinal axis. Difference between the elements in the amount of body rotation around the longitudinal axis is more than ½ turn or

207.2% in hips rotation and 213.3% in shoulder rotation (see Figure 7).

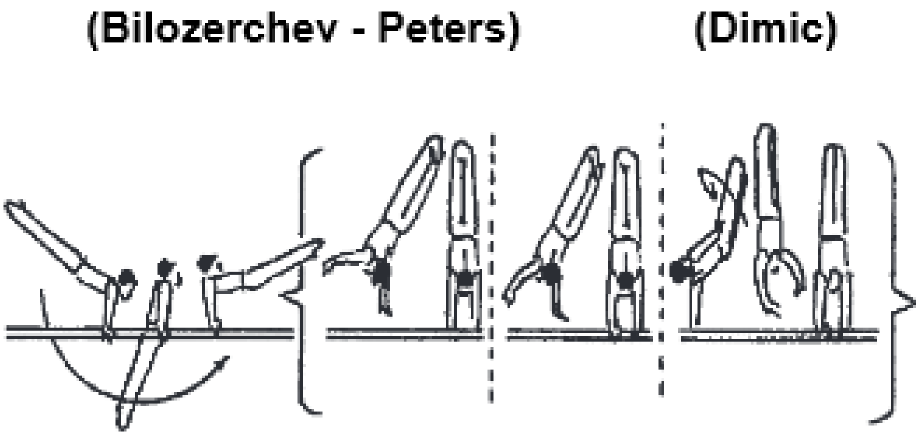

Figure 1. Box I.10 in Men's artistic gymnastics Code of Points (FIG, 2013).

Figure 2. Element "Dimic" on parallel bars.

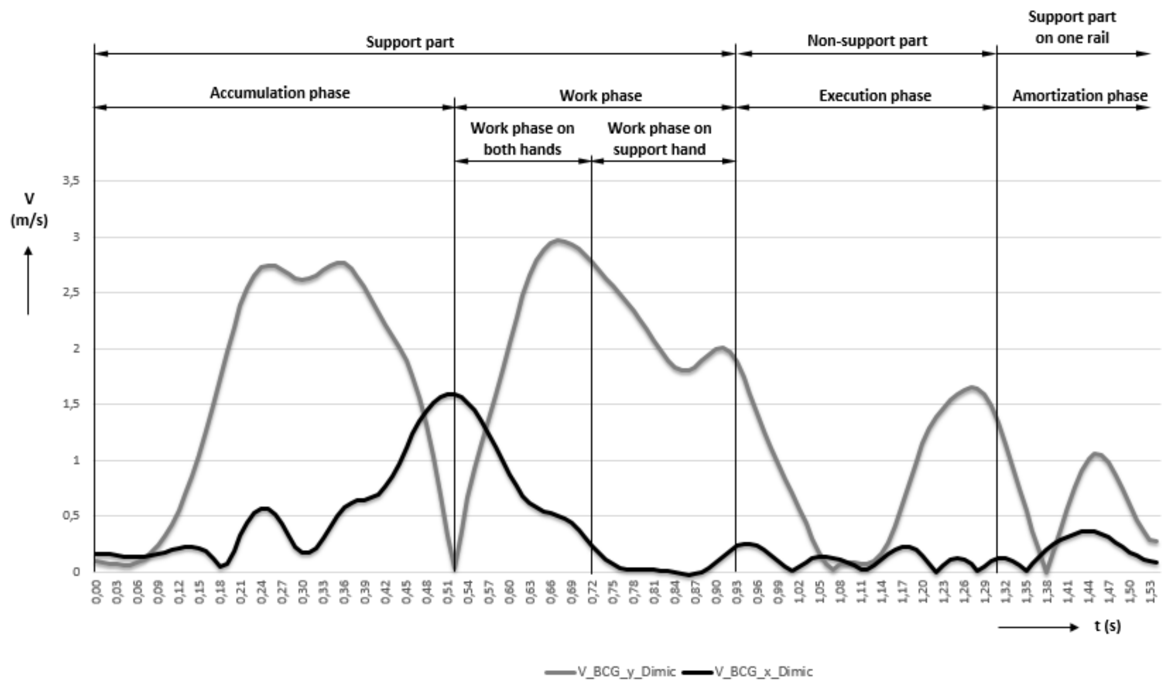

Figure 3. Velocity of the body centre of gravity (BCG) in vertical and horizontal axes in element "Dimic" and description of different phases of an element according to the Smolevskij's (1992) model.

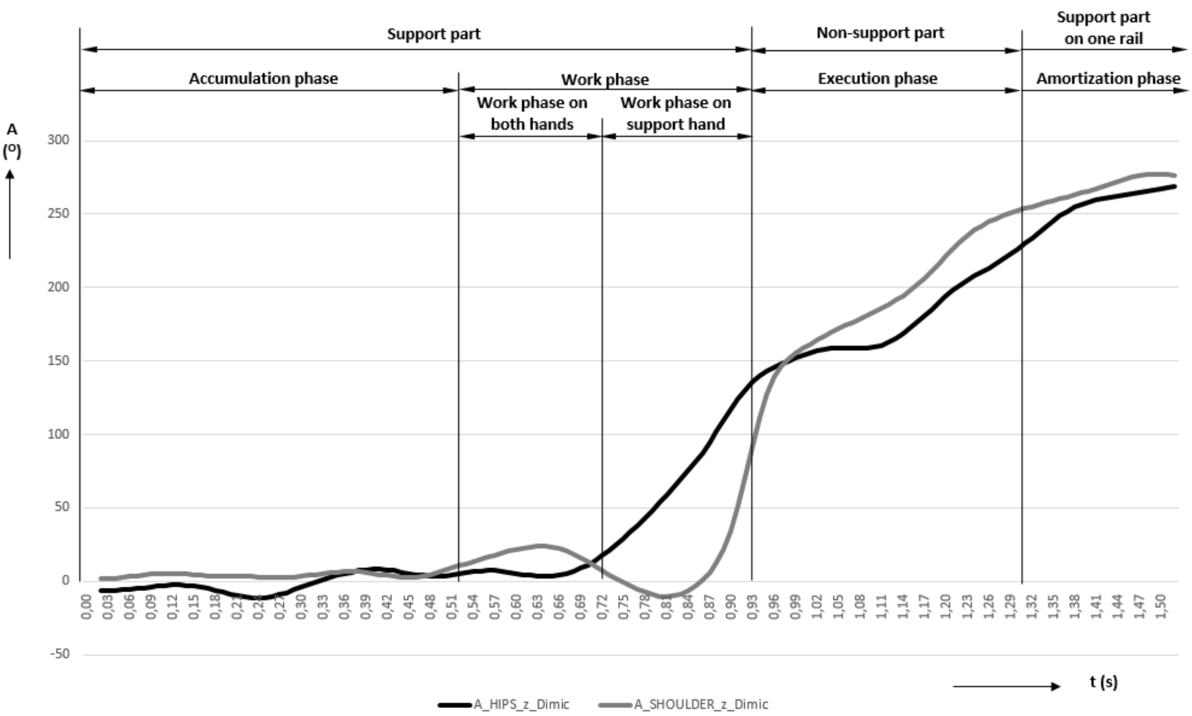

Figure 4. Rotation of shoulders and hips around the longitudinal axis.

elements.

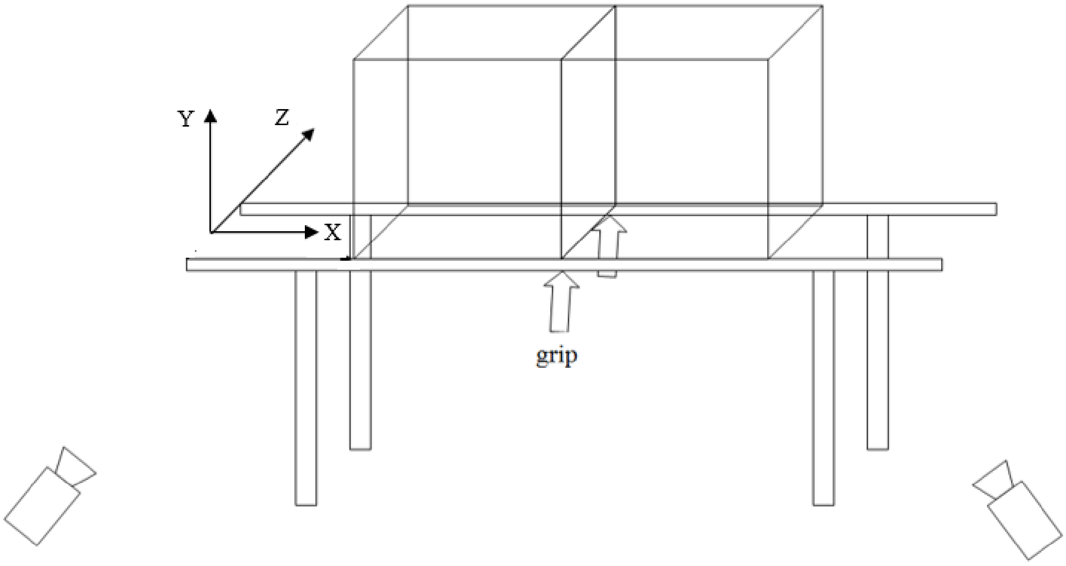

Figure 5. Space calibration.

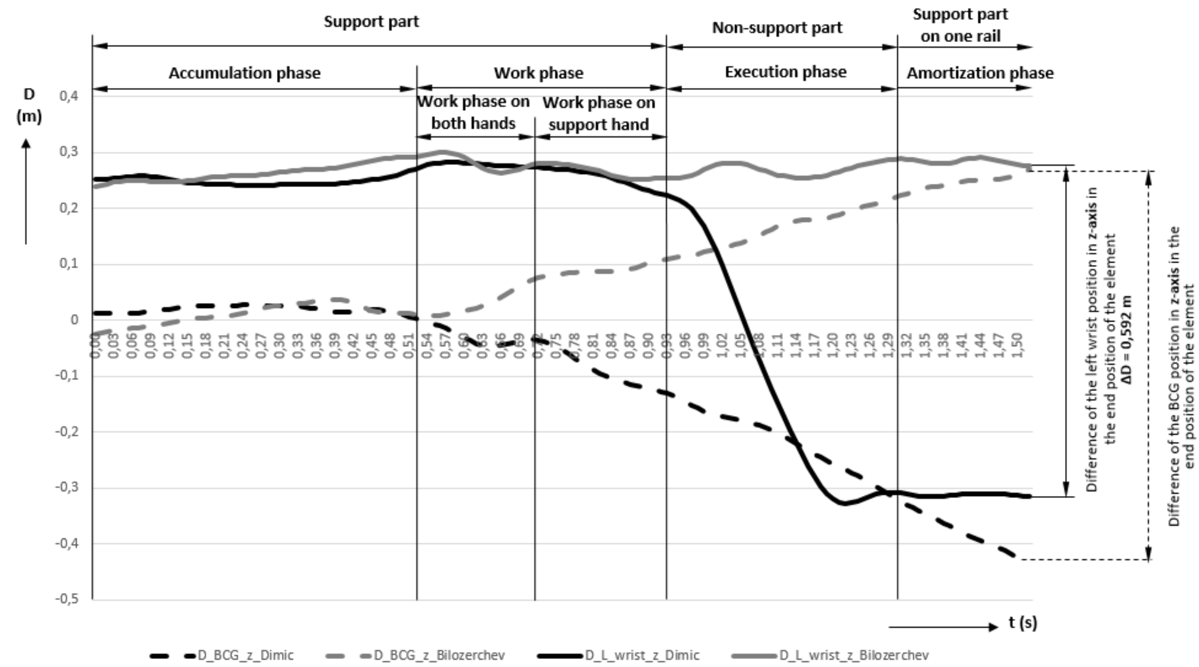

Figure 6. Comparison of paths of BCG and supporting arm (left wrist) during both

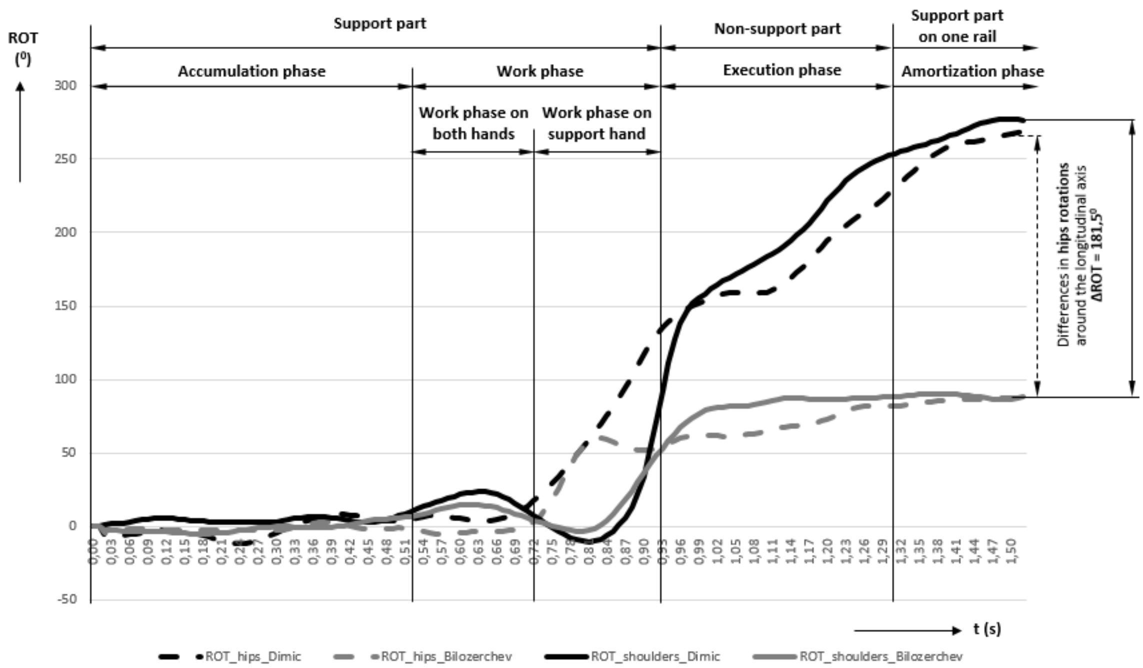

Figure 7. Comparison of hips and shoulders rotation around the longitudinal axis during both elements.

Table 1
Comparison of the evaluation of elements with similar movement structure and different quantity of turns around the vertical axis.

Element group (apparatus)	Element	Turns around vertical axis in (°)	Box Number (FIG, 2013)	Difficulty
Swing backward with turn (parallel bars)	Swing backward with ½ turn hop	180°	I.68	B
	Swing backward with ¾ turn hop to handstand	270°	I.69	C
	Swing backward with 1/1 turn hop to handstand	360°	I.70	D
Backward uprise to handstand (parallel bars)	Backward uprise to handstand	0°	II.26	B
	Backward uprise with ½ turn hop to handstand	180°	II.27	C
	Backward uprise with ¾ turn hop to handstand on 1 rail	270°	II.28	D
Flying giant swing backward with turns (high bar)	Flying giant swing backward with 1/1 turn	360°	I.45	C
	Giant swing backward with hop 3/2 turn	540°	I.63	C
Tkatchev (high bar)	Tkatchev stretched	0°	III.16	D
	Tkatchev stretched with ½ turn	180°	III.17	E
	Tkatchev stretched with 1/1 turn	360°	III.18	F

DISCUSSION

An analysis of kinematic parameters of movement in the element “Dimic” on parallel bars has revealed that the skill is performed in support on the bars and consists of the support and non-support parts. In the support part, when gymnast moves from handstand to the high forward swing, the activity of the gymnast aims to produce sufficient linear and angular velocity in order to execute desired movement in a non-support part. During the non-support part, gymnast moves the BCG and all other body parts approximately 0.7m away from the supporting arm (see Figure 6) and rotates the body around the longitudinal axis by approximately ½ turn (see Figure 4). Combined with the rotation of body on a supporting arm in the support part of the skill, the total rotation equals to approximately ¾ turn (see Figure 7). Movement in the non-support part of the skill mainly depends on the efficient swinging in the support part of the skill (Kolar, Andlovic-Kolar & Štuhec, 2002; Manoni, et al., 1992a; 1992b). Movement in the non-support part of the skill represents a basis for the evaluation and classification of the skill by the experts according to the difficulty aspect and structural characteristics of the skill. The experts from the FIG MTC have matched the element “Dimic” in the Code of Points (FIG, 2013) with the “Bilozerchev” elements both from the aspect of difficulty and from the structural complexity of the movement. The authors of the study consider this act as incorrect, as the movement of the skills differs in both difficulty and structure, particularly in the non-support part of the elements.

A comparison of kinematic parameters of movement between the “Dimic” and “Bilozerchev” elements revealed important differences in the non-support part of the skills, which are crucial in both elements and determine their structural description, complexity and difficulty. Successful execution of “Dimic” skill requires from the gymnast to perform larger movement of the BCG and other parts of the body in space (translation). Additionally, the gymnast needs to perform approximately ½ turn more (rotation) than in the skill “Bilozerchev”. Findings indicate that these two skills have from the kinematic characteristics point of view ***different motor structure*** and that “Dimic” skill is **more *complex*** than “Bilozerchev” skill. Both kinematic characteristics of movement (path in meters and change of angle in degrees) are in both skills mostly performed in a non-support part (i.e., execution phase). According to the principles of conservation of linear and angular momentum, both quantities remain constant in a non-support part (as there are no external forces acting upon them). Consequently, it is evident that successful realisation of »Dimic« skill requires considerably larger amount of linear (translation of body) and angular momentum (rotation of body) in comparison to skill “Bilozerchev” (in the element “Dimic”, the displacement of BCG is larger by 0.181m or 70%, the displacement of supporting left arm is larger by 0.595m, the rotation of hips is larger by 181.5° or 207.2% and the rotation of shoulders is larger by 188.1° or 213.3%). It can be concluded that “Dimic” skill is ***more difficult*** than the “Bilozerchev” skill.

Findings in kinematic characteristics between the skills confirm the hypothesis that the initial classification of “Dimic” skill in the Code of Points (FIG, 2013, p. 116) seems incorrect and unjust to the gymnasts who can perform both skills and wish to include them in their competition routines. Classification also appears inconsistent with some other decisions about placing the skills into the Code of Points (FIG, 2013). Namely, skills with the execution part being performed mostly in the non-support part that increase in the amount of turns around the longitudinal axis, are characteristically awarded higher difficulty or/and structurally into different, independent boxes in the Code of Points (FIG, 2013). Some examples of such classification are presented in Table 1.

CONCLUSION

Development of new skills in artistic gymnastics is a process linked to a technical knowledge of individual gymnast, theoretical knowledge of a close coaching team and the creativity of everyone involved in the process. A result of such process is a new gymnastics skill that has to be successfully performed in an official FIG competition in order to be evaluated through the decision of the FIG MTC. Evaluation process is an important part of the process as it determines the difficulty of the skill and its classification in the FIG Code of Points according to the structural characteristics of the skill. Evaluation process is carried out independently of the creators of the new gymnastics skill and entirely depends on the group of experts within the FIG TC, i.e., on their knowledge in the area of rational judgement of structural complexity of gymnastics skills.

The article used a method of biomechanical modelling and an analysis of kinematic characteristics of movement in order to present a new gymnastics element "Dimic" on parallel bars. According to the opinion of authors, the skill seems incorrectly classified by the FIG MTC in the Code of Points (FIG, 2013, p. 116). Namely, a comparison with skills that the FIG MTC members matched in both difficulty and structural complexity revealed that the "Dimic" skill is more complex from the aspect of kinematic characteristics and provision of linear and angular momentum than the skill "Bilozerchev". Furthermore, the study revealed that the classification of "Dimic" skill did not follow the guidelines for classification of other skills, which are similar in the type of movement, but differ one from another in the amount of rotation around the longitudinal axis in a non-support part of the skill. As a result, the authors suggest that the FIG MTC places the element "Dimic" in a separate box in Code of Points and classify the skill as a D-value element.

Finally, the authors consider the classification of new skills and evaluation of their difficulty to be a complex process, which should not be left only to the subjective judgement of experts. The process should be primarily based on the use of methods that allow precise understanding of technical characteristics and motor structure in new skills. The article presents such method and its use.

REFERENCES

Čuk, I. (1995). Kolman and Pegan saltos on high bar. In Jošt B. (Eds.), *Kinematična analiza gibanj v izbranih športnih panogah* [Kinematic analysis of movement in selected sport disciplines. In Slovenian.] (p. 195-198) Ljubljana: University of Ljubljana, Faculty of sport.

Čuk, I. (1996). *Razvoj in analiza nove gimnastične prvine (seskok podmet salto naprej z bradlje)* [Development and analysis of the new gymnastic element (Cast to salto forward from the parallel bars). In Slovenian.]. Unpublished doctoral thesis, Ljubljana: Faculty of Sport, University of Ljubljana.

Čuk, I., Atiković, A., & Tabaković, M. (2009). Tkachev salto on high bar. *Science of Gymnastics Journal*, *1*(1), 5-15.

Davis, J. (2005). Under somersaults on parallel bars. *Gym Craft*, *14*, 6–7.

Dempster, W.T. (1955). *Space Requirements of the Seated Operator*. WADC Technical Report 55-159, Ohio: Wright-Patterson Air Force Base.

Gervais, P. & Dunn, J. (2003). The double back salto dismount from the parallel bars. *Sports Biomechanics*, *2*, 85-101.

Heng, T. (2007). Kinematical descriptors of circles on short pommel horse in men's artistic gymnastics. *Journal of Biomechanics*, *40*, S741.

Hiley, M. J., Wangler, R., & Predescu, G. (2009). Optimization of the Felge on Parallel Bars. *Sports Biomechanics*, *8*(1), 39-51.

Fédération Internationale de Gymnastique - FIG (2013). *Code of Points for Men Artistic Gymnastics Competitions* (2013 Edition) Available at: http://www.figgymnastics.com/ publicdir/rules/files/mag/MAG%20CoP%20 2013- 2016%20(FRA%20ENG%20ESP)%20 July %202015.pdf. Accessed 23.03.2016.

Kolar, E., & Piletič, S. (2005). Dvojni stegnjeni salto z droga z obratom za 720°. [Double stretch somersault from high bar with turn for 720°. In Slovenian]. In Kolar, E., & Piletič, S. (Eds.) *Gimnastika za trenerje in pedagoge 1* [Gymnastics for coaches and teachers 1. In Slovenian] (p. 19-28). Ljubljana: Slovenian Gymnastics Federation.

Kolar, E., Andlovic-Kolar, K., & Stuhec, S. (2002). Comparative analysis of selected Biomechanics characteristics between a support backward swing and support swing for the 1¼ straddle-piked forward salto on the parallel bars. *Sports Biomechanics*, *1* (1), 69-78.

Kolar, E, Samardžija Pavletič, M., & Veličković, S. (2015). Importance of biomechanical modelling for technical preparation of a gymnast. In: Samardžija Pavletič, M., & Bučar Pajek, M. (Eds.) *Scientific programme, plenary lectures, invited proceedings, book of abstracts and book of proceedings* (p. 9-30). Ljubljana: Slovenian Gymnastics Federation.

Kolar, E., Piletič, S., Kugovnik, O., Andlovic-Kolar, K., & Stuhec, S. (2005). Primerjava kinematičnih spremenljivk dobrih in slabih izvedb seskoka z bradlje. [A comparison of kinematic characteristics of good and bad executions of dismount from parallel bars. In Slovenian]. In Kolar, E., & Piletič, S. (Eds.) *Gimnastika za trenerje in pedagoge 1* [Gymnastics for coaches and teachers 1. In Slovenian] (p. 34-44). Ljubljana: Slovenian Gymnastics Federation.

Linge, S., Hallingstad, O., & Solberg, F. (2006). Modelling the parallel bars in Men's Artistic Gymnastics. *Human Movement Science*, *25*(2), 221-237.

Manoni, A., De Leva, P., Carvelli, E., & Mallozzi, L. (1992a). Biomechanical analysis of a double backward salto at the parallel bars. In G. P. Brueggmann, & J. K. Ruhl (Eds.), *Proceedings of First International Conference Biomechanics in Gymnastics* (p. 475-485). Cologne: Bundesinstitute fur Sportwissenshaft.

Manoni, A., De Leva, P., Carvelli, E., & Mallozzi, L. (1992b). Comparative biomechanical analysis of three different forward saltos at the parallel bars. In G. P. Brueggmann, & J. K. Ruhl (Eds.), *Proceedings of First International Conference Biomechanics in Gymnastics* (p. 487-497). Cologne: Bundesinstitute fur Sportwissenshaft.

Marinšek, M., Kolar, E., Piletič, S., & Kugovnik, O. (2006). Kinematične značilnosti prvine diamidov na bradlji. [Kinematic characteristics of Diamidov on parallel bars. In Slovenian]. In Kolar, E., & Piletič, S. (Eds.) *Gimnastika za trenerje in pedagoge 2* [Gymnastics for coaches and teachers 2. In Slovenian] (p. 39-56). Ljubljana: Slovenian Gymnastics Federation.

Marinšek, M., & Kolar, E. (2007). A comparison of selected kinematical characteristics between successful attempts of elements Diamidov, Diamidov with 180° turn and Diamidov with 360° turn. *Kalokagathia*, *47*, (3/4), 138-148.

Matveev, L.P. (1977). *Osnovi sportivnoj trenirovki*. [Basics of sports training. In Russian]. Moskva: Fiskultura i sport.

Opavsky, P. (1987). *Osnovi biomehanike*. [Basics of biomechanics. In Serbian]. Beograd: Naučna knjiga.

Prassas, S. (1994). Technique analysis of the back toss on the parallel bars performed by elite gymnasts. In Barabas, A., & Fabian, G. (Eds.) *Proceedings of the 12 International Symposium on Biomechanics in Sports* (p. 249-251). Budapest: Hungarian University for Physical Education.

Prassas, S. (1999). On Dismounts, Twists, Somersaults, etc., or Why it is Difficult to Do that Double Back Layout

Somersault? *International Journal of Sports Biomechanics* (6), 148-157.

Prassas, S., & Ariel, G. (2005). Kinematics of giant swings on the parallel bars. In Wang, Q. (Eds.) *Proceedings of the 23 International Society of Biomechanics in Sports*. Beijing: The China Institute of Sport Science, 951-953.

Prassas, S., Ostarello, J., & Inouye, C. (2004). Giant swings on the parallel bars: a case study. In Lamontagne, M., Gordon, D., Robertson, E., & Sveistrup, H. (Eds) *Proceedings of the 22 International Symposium on Biomechanics in Sports* (p. 345). Canada: University of Ottawa.

Smolevskij, V.G. (1992). *Lecture phase constitution of gymnastics, Structure of technical errors, Control and self-control*. Great Britain.

Tsuchiya, J., Murata, K., & Fukunaga, T. (2004). Kinetic analysis of backward giant swings on parallel bars. *International Journal of Sport and Health Science*, *2*(1), 211-221.

Veličković, S. (2005). *Definisanje kinematičkog modela tehnike izvođenja najsloženijih gimnastičkih vežbi* [Defining a kinematic technical model of executing the most difficult gymnastics skills. In Serbian]. Unpublished Doctoral dissertation thesis. Novi Sad: Faculty of physical culture, University of Novi Sad.

Veličković, S., Kolar, E., Kugovnik, O., Petković, D., Petković, E., Bubanj, S., Bubanj, R., & Stanković, R. (2011). The kinematic model of basket to handstand on the parallel bars. *Facta Universitatis: Series Physical Education And Sport, 9* (1), 55-68.

Veličković, S., Kolar, E., Kugovnik, O., Madić, D., Aleksić – Veljković, A., & Paunović, M. (2013). Prediction of the success of the basket to handstand on parallel bars based on kinematic parameters – a case study. *Facta Universitatis: Series Physical Education And Sport*, *11*, (1), 9-21.

Yeadon, M.R. (1999). Learning how to twist fast. In Prassas, S., & Sanders, R. (Eds.) *Proceedings of the XVII International Symposium on Biomechanics in Sports* (p. 49-59). Perth: Edith Cowan University.

Corresponding author:

Edvard Kolar
University of Primorska
Science and Research Centre
Institute for Kinesiology
Garibaldijeva 1
6000 Koper
Slovenija
tel: +386 41 376 381
E-mail: edvard.kolar@olympic.si