BIOMECHANICAL CHARACTERISTICS OF STAG LEAP WITH BACK BEND OF THE TRUNK: A CASE STUDY

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Case study

Abstract

Biomechanical considerations as reflected in correct or incorrect technique, particularly in all gymnastic disciplines are more than undoubted. The stag leap as a variation of split leaps is one of the fundamental gymnastics skill and a key movement in the development of elite female gymnasts. The aim of the study was to analyse the kinematic characteristics of the stag leap with back bend of the trunk performed in rhythmic gymnastics and simultaneously find out the explosive power regarding this particular element. A member of Slovakian national team was involved in the study. Kinematic characteristics of the element were analysed. A capture system consisting of 8 infrared cameras were employed to collect the data. The explosive power of the lower limbs were diagnosed by a jump ergometer with 2 standardized tests: vertical counter-movement jump with the fixation of the arms and 10-second repetitive vertical jumps with arms movements. In addition, the explosive power of the lower limbs was also observed in the flight phase of the element. The results in 10-second repetitive jumps show the highest value of gymnast centre of mass 46.4 cm, contact time 0.195 s and the best active output in the flight phase 58.3 W.kg^{-1}. While performing the difficulty element, slightly different data were observed due to the complexity and more demanding motor coordination of both upper and lower body segments: the highest value of gymnast centre of mass was 40.8 cm, contact time 0.209 s and the output in the active flight phase 52.8 W.kg^{-1}.

Keywords: *rhythmics, kinematic characteristics, explosive power, 10-second repetitive jumps, vertical counter-movement jump.*

INTRODUCTION

Rhythmic gymnastics (RG) is define as an aesthetic, purely feminine Olympic sport that combines the sporting art of physical capacities with the art of dance. To achieve a top performance level it is important to master the difficulty of the applicable rules, the technique of demanding elements or equipment and the ability to connect all components of rhythmic gymnastics with music, style of music, rhythm, pace, etc. The sports performance is the result of all these factors of high intensity and in the evaluation, in addition to the technical demonstration, puts great emphasis on the aesthetic demonstration (Miletić, Katić & Males, 2004). As it has been already scientifically approved, the most limiting abilities in RG are the explosive power and flexibility, mostly of lower limbs, which affects performance of a gymnast to the great extent. According to Hutchinson et al. (1998) RG belongs to the "high jump-challenging sports". In addition, as stated by Ashby & Heegaard (2002), jumps are fundamental movements, requiring complex motor coordination of both upper and lower body segment.

One of the most important factors in RG is technique. The correct “model” technique and difficulty element forms is specified in the RG Code of Points, updated for each Olympic cycle. The overall motor coordination of both the upper and lower body limbs (Ashby & Heegaard, 2002) is an important for the correct execution. In addition to the technical demonstration and flexibility, the explosive power of the lower limbs is an essential part of the performance in RG, which is required to perform take-off of difficulty and choreography elements. It is also considered one of the most important indicators for talent identification (Di Cagno et al., 2008). Flexibility, explosive power, reaction time and anthropometric characteristics account for 41% success in performing the basic elements of difficulty in RG, while the frequency of movement and the volume of performing specific manipulation with the requisite (ball, hoop, ribbon, clubs, rope) is 26% (Miletić, Katić & Males, 2004). In addition to the technical skills, performance in rhythmic gymnastics also affects several fitness and coordination abilities. The lack of strength, mobility and movement accuracy can lead to catastrophic performance (Brooks, 2003). During the intense training sessions gymnasts are asked to perform routines while fatigued, and to find the best compromise among technical effectiveness, safety, and high intensity effort (Sands et al., 2011). Thus, the high level of the basic requirements of fitness is necessary for the success in learning of skills.

The functional diagnosis and analysis of the top-level athlete’s movements using various training aids must be an essential part of their training. To improve sports performance in RG it is necessary to analyse constantly the exercise patterns and to diagnose the limiting factors. Despite growing popularity of RG, still there is a lack of biomechanical analyses in literature, regarding the techniques of the specific difficulty elements (Cicchella, 2009). Nevertheless, the most part of RG coaches have a great difficulty to analyse the most common errors while performing jumps and leaps (Sousa & Lébre, 2010). Doubtlessly, the use of technological equipment and methods leads to an improvement in the training process and thus the competition performance. Thanks to the three-dimensional (3D) analysis we can study the movement in more details and find execution errors that are often invisible at the speed by a naked eye, and then affect and correct the technique of the elements. It is the biomechanics that is the science that discovers the cause of erroneous execution before it we can identify it (Sands, 2011).

The aim of the study was to analyse the kinematic characteristics of the stag leap with back bend of the trunk performed in rhythmic gymnastics and simultaneously find out the explosive power regarding this particular element. The study was approved by the Ethics Committee of FPES CU in Bratislava.

METHODS

The study was conducted by a senior Slovakian team member in RG, a multiple national champion and a participant of the European and World Championships (age 23 years; body weight 62 kg; body height 176 cm). The basic difficulty element - *the stag leap with back bend of the trunk* (Fig. 1) has been investigated. According to the actual FIG RG Code of Point (FIG, 2017) this particular element is a typical jump with a trunk bend backwards with a difficulty value of 0.3 points. An angle between the legs (thighs) of at least 180° is required, the maximum bend of the front lower limb and the head in the back bend must be in proximity to some part of the lower limb; contact under current rules is not required.

Figure 1. Stag leap with back bend of the trunk (FIG, 2017)

To execute the element properly 4 phases must be performed fluently, with no hesitation between:

1st - preparatory phase,
2nd - take-off phase,
3rd - flight phase,
4th - landing phase.

The gymnast began to perform the element with the preparatory phase: from the standing position, legs are together and the arms are streched out of the side. The gymnast then performs two steps forward and jumps from one food into the demi-squat with arms close to the body. Preparatory phase is followed by 2-feet take-off "as fast and as high as possible", so the elastic energy is used. Once the gymnast is airborne in the flight phase she must show the correct form of the element - stag position with back bend of the trunk. To land properly with no errors she must slow down the speed to zero.

Testing and data were conducted in a laboratory environment. We obtained the data by analysing the kinematic variables of the element, particularly the spatial and temporal characteristics. To record the movement and to get precise and correct data, we used eight high-speed Blaster company cameras scA640-120gc, which were arranged to capture the entire movement of the element. The recordings were focused from three different angles. The entire process of recording and storing has been done in Simi Motion 3D program (the German company Simi Reality motion Systems GmbH based in Unter-schleissheim). The difficulty element was executed on a dynamometric plate. Before the recording the element, 12 important anthropometric points has been identified on the bodies of the gymnasts where markers were placed to serve for better visibility when recording and depicting the angles between the body segments in CorelDraw 12 program (Fig. 2).

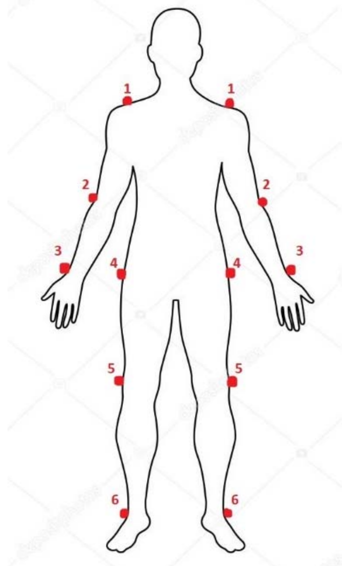


Figure 2. Anthropometric points - marker placement of the gymnast (R = right, L = left) 1. L and R arms - the highest lateral point on the acromial extension; 2. L and P elbows - a point at the edge of the head of the spoke bone; 3. L and P wrists - a point at the edge of the head of the spoke bone; 4. L and R hips - the highest point of the head of the thighbone; 5. L and R knees - a point on the outer epicondylitis of the fistula; 6. L and R ankles - a point on the outer ankle.

The Fitro Jumper (Zemkova & Hamar, 2004), Fig.3 has been used for data acquisition, measurement and diagnosis of the take-off explosive power. The explosive power of the lower limbs were diagnosed by use of a jump ergometer with 2 standardized tests: vertical counter-movement jump with the fixation of the arms and 10-second repeated vertical jumps with arms movements (Bosco et al., 1983). In addition, the explosive power of the lower limbs was also observed during the difficulty element. The gymnast performed 3 separate attempts of the stag leap with back bend of the trunk. The kinematic characteristics in the flight phase of the element was detected and analysed. A Simi Motion capture system were employed to collect the following data: the height of the centre of mass (CoM) in the flight phase (cm), the contact time of the feet (s) and the output in the active phase of take-off ($W.kg^{-1}$).

Figure 3. Fitro Jump ergometer (Zemkova & Hamar, 2004).

All measurements were done at the end of preparatory period of the season. In this phase gymnast has been trained 6 times per week, 6 hours per day. Weekly training load contained specific physical preparation, including dance and gymnastic skills. The distribution of individual training components in the weekly microcycle was as follows: endurance – 25 %, speed – 12,5 %, strength – 12,5 %, coordination – 12,5 %, gymnastic skills training + dance preparation – 37,5 %.

RESULTS

Analyse of the stag leap with back bend of the trunk. As stated, kinematic characteristics of the stag leap with back bend of the trunk has been obtained by analysing 4 phases of the element: 1st - preparatory phase, 2nd - take-off phase, 3rd - flight phase, 4th - landing phase. The gymnast's attention during each phase of the jump is not equal. In general, the attention is higher during the approach and the flight, and lower during the take-off and the landing. Better preparatory phase helps the gymnast in better control of the movements during the flight. Longer flight phase allows the gymnast to reach a correct body shape and form of the element.

The analyse of temporal characteristics shown that from the moment of the first step in preparatory phase up to the landing, elapsed time was 3.090 s. In the table 1 duration of each phase is demonstrated. As expected, the shortest phase with duration of 0.120 s was the take-off.

Table 1
Duration (s) of the stag leap from the preparatory phase to the moment of the landing (the 1st foot contact).

Phases of the element	Duration
Preparatory phase	1.710
Take-off phase	0.120
Flight phase	0.500
Landing phase	0.760

Regarding the *spatial characteristics*, we analysed the angles between the individual body segments as follows:

- Head - middle of the arms – middle of the hips
- Shoulder joint - elbow joint - wrist
- Hip joint - shoulder joint – elbow joint
- Hip joint - knee joint - ankle joint
- Knee joint - hips - knee joint
- Ankle joint - hip joint - ankle joint
- Middle of the arms - middle of the hips - mat
- Hip joints - shoulder joints

At each phase, we have chosen those angular changes that are important and crucial for execution of the element.

In the *preparatory phase* the detected flexions were: hip joint - knee joint - ankle joint; hip joint - shoulder joint - elbow joint; hip joint – shoulder joint. Results show a slight difference between the right and left body segments, table 2.

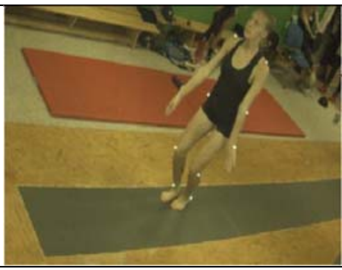
In the *take-off phase* (the last contact before the flight) we analysed hip joint – shoulder joint; hip joint - knee joint - ankle joint; hip joint - shoulder joint - elbow joint; middle of the arms - middle of the hips – mat; head flexion backwards. Results are shown in table 3.

Flight phase is the most important regarding the minimum requirements for the difficulty value. Spatial changes have been analysed between joints: hip – right knee – right ankle; hip – shoulder – elbow; right knee – hip – left knee; hip – shoulder; head flexion backwards (table 4). According to the actual FIG RG rules (FIG, 2017) the required angle between the legs (thighs) must be at least 180° during the flight phase. This is what the angle of the knee joint of the anterior lower limb - hips - knee joint of the posterior lower limb represents. The gymnast didn´t meet the minimum requirement, and she reached the value of angle 160°. Another requirement according to the FIG rules is the maximum back bend with the head closest as possible to any part of the lower limb. As it is shown in table 4, gymnast achieved an insufficient back bend angle 133°, but a maximum flexion in the right knee joint (anterior lower limb).

Many errors in execution can occur in *landing phase*. As demonstrated in table 5, these angular changes were observed regarding the correct performance of the element: hip – right knee – right ankle; right ankle – hips – left ankle; shoulder – hip; hips – shoulder – both elbows; head flexion backwards.

In the landing phase, table 5, at the first contact with the floor, the shoulders with the hips remain almost the same as in the previous flight phase, 136° versus 133° respectively. This is due to the fact that the shoulders remain slightly tilted. Forward flexion of the trunk in this position could cause a large step after completing the element, and thus an error in execution.

Table 2
Angles (°) between individual body segments in the preparatory phase; R = right, L = left.



Body segment	Range between the segments
Hip - knee - ankle	R = 127; L = 126
Hip - shoulder - elbow	R = 11; L = 13
Hip – shoulder	170

Table 3
Angles (°) between individual body segments in the take-off phase; R = right, L = left.

Body segment	Range between the segments
Hip - knee - ankle	R = 172; L = 175
Hip - shoulder - elbow	R = 76; L = 66
Hip – shoulder	172
Middle arms – middle hips – mat	85
Head flexion backwards	170

Table 4
Angles (°) between individual body segments in the flight phase; R = right, L = left.

Body segment	Range between the segments
Hip – R knee – R ankle	56
Hip - shoulder - elbow	R = 133; L = 113
R knee – hip – L knee	160
Hip - shoulder	133
Head flexion backwards	102

Table 5
Angles (°) between individual body segments in the landing phase; R = right, L = left.

Body segment	Range between the segments
Hip – R knee – R ankle	168
R ankle – hips – L ankle	98
Hip - shoulder	136
Hip – shoulder – R & L elbow	R = 166; L = 85
Head flexion backwards	151

Table 6
CoM height (cm) in vertical counter-movement jump with fixation of the arms.

	CoM height
Attempt no.1	38.5
Attempt no.2	39.0
Attempt no.3	41.8

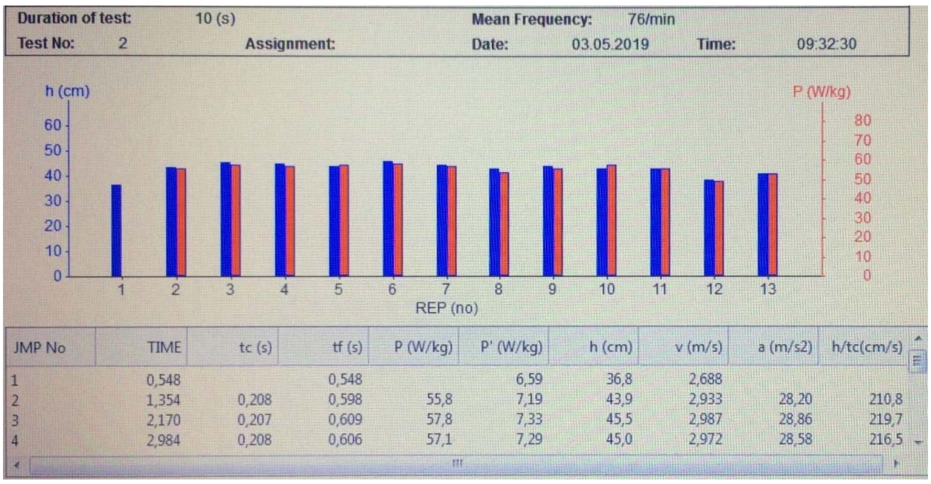


Figure 4. Record of series of 10-second repetitive vertical jumps with arms movement
■ = the height reached by the gymnast (cm); ■ = the achieved performance in the active take-off phase (W.kg^{-1}).

Table 7
Contact time (s), *CoM height (cm) and output* (W.kg^{-1}) *in the active phase in 10-second repetitive vertical jumps with arms movement, 3 best values.*

Contact time	CoM height	Output in the active phase
0.195	46.4	58.3
0.200	45.5	57.8
0.205	45.0	57.7

Table 8
Contact time (s), *CoM height (cm) and output* (W.kg^{-1}) *in the active phase in the stag leap with back bend of the trunk on the platform of jump ergometer (3 attempts).*

Contact time	CoM height	Output in the active phase
0.213	34.1	46.0
0.209	40.8	52.8
0.198	36.2	46.4

Explosive power measurements. Explosive power, as a combination of force and velocity, depends on how quickly the gymnast can develop maximal force within the neuromuscular system. As stated at beginning, RG belongs to the "high jump-challenging sports". Speed in development of force is crucial to success in jumps not only in RG. High and graceful jumps are required in each gymnastic routine, independently from the use of requisite or apparatus.

The explosive power of the lower limbs were diagnosed by use of a jump ergometer with 2 standardized tests. To detect a maximal effort of the gymnast during the single jump *the vertical counter-movement jump with the fixation of the arms has been used*. Gymnast performed three attempts, with enough time for rest. The height of the CoM was measured (table 6).

The 10-second repetitive vertical jumps with arms movements provide much more information about lower limb power than a simple vertical jump test for height. As the gymnast might perform different jumps, leaps and hops during the routine, the force and rate of acceleration become major priorities.

From the series of 10-second repetitive vertical jumps with arms (Fig 4), the 3 best values of the contact time; the CoM height of the flight phase; and the output in the active take-off phase (from the first foot contact with the mat to the last foot contact with the mat) were recorded (table 7).

In addition, the explosive power of the gymnast's lower limbs was also observed during the difficulty element. The gymnast performed three attempts of *the stag leap with back bend of the trunk on the platform of jump ergometer*. We studied the same variables as in the previous test: the contact time; height of the flight phase, e.g. CoM height; and the output in the active take-off phase (table 8).

The gymnast began to perform the element with preparatory phase, followed by 2 feet take-off "as fast and as high as possible", so the elastic energy is used. The output in the active take-off phase together with complex coordination of the body segment play an important role in reaching the dynamic jump. As it shown in table 8, the gymnast achieved the best output value in the second attempt (52.8 W.kg^{-1}). Probably, the best output value had also impact on the highest CoM height of the jump in the same attempt (40.8 cm).

DISCUSSION

The stag position in the air, together with split and ring, is the most frequently performed in RG. Although, the difficulty value of the element observed in this study is only 0.3 point (maximum = 1.0 point), we considered this jump as one of the most demanding, due to several reasons, e.g. numbers of articulations, flexions of the body segments involved while performing the element, as well as requirements on explosiveness and flexibility regarding the perfect execution. Gymnast during take-off phase must coordinate all body segments (leg, trunk, arms and head) in order to achieve the maximum take-off. In the flight phase, at one moment, gymnast must make a maximum range in the hip joint, at least 180 ° between the lower limbs, a maximum flexion in the knee joint of the anterior lower limb and a maximum extension in the knee joint of the posterior lower limb. A maximum back bend of the trunk and head in proximity to some part of the lower limb are required. As far as the upper limbs are concerned, the most technically optimum is that the upper limb that is opposed to the anterior lower limb is raising forward and the second one is pointing towards the ankle of the posterior lower leg. This allows the gymnast to fix her shoulders symmetrically, with no technical collision (Selecká, 2019). Given all these requirements, both take-off and landing are very demanding, which requires proper coordination of all movements and strength of the abdominal muscles and back. While landing, it is important that the gymnast does not flex trunk forward or backward, but stays straight, which is not easy after the maximum back bend. Additionally, the gymnast must slow down the landing with external forces, jumps down over the toes to the semi-squat, transfer the weight of the body to the lower limb and while extending the knee, take a step forward by posterior lower limb. This will help straighten the entire body and prevent heavy landing and possible injuries. For a technically correct element, proper coordination of all movements and body parts, explosive power of lower limbs and sufficient flexibility are required.

Despite the “popularity” of the stag leap in gymnastics only few studies deal with the biomechanical characteristics of this particular difficulty element or the similar variations in rhythmic gymnastics (Cicchella, 2009; Sousa & Lebre 2010, Purenović et al., 2010; Rodríguez & Rodríguez, 2018) or other related gymnastic disciplines (Mkaouer et al., 2012; Olej et al., 2018; Kyselovičová et al., 2019). In general, studies mainly focused on the analysis of individual phases of the element, underlining the flight phase due to difficulty requirements. However, the decisive part is the take-off, in which the short, maximum muscular and voluntary effort of the gymnast is concentrated. In addition, most errors occur at take-off and are usually due to incorrect force application.

Indeed, the height of the jump or the leap depends on the depth of the semi-squat in preparatory phase just before the take-off. As it has been found in the study of Purenović et al. (2010) the semi-squat also depends on the strength of the leg flexor muscles. By increasing the depth of the semi-squat, up to the optimal value, gymnast increases the height of the jump or the leap, although excess semi-squat decreases the resulting height. Our results show the average of the knee articulations (angle between hips – knees – ankles) 126.5°. As suggested by Jastrjembskaia & Titov (1998) the optimal semi-squat depth is 112º. Variations ±20º reduce the resulting height.

The take-off sub-phase gives to the gymnast's CoM a vertical speed. As the speed is greater, it causes a greater flight’s height. According to Zemkova & Hamar (2004), the take-off in high-jump challenging athletes does not last more than 0.2 s. Therefore, the power an athlete is able to develop in a relatively short time is decisive. Our gymnast also fluctuated around this value, reaching the best contact time 0.195 s in *take-off phase of stag leap with back bend of the trunk* and 0.198 s in 10-second repetitive vertical jumps with arms movement.

Similar results are also found in the study by Cagno et al. (2008). The authors analysed the length of contact time of the feet with the mat at the Optojump and the length of the flight phase of the Italian gymnasts during the *split leap with the trunk bended backwards*. The results of contact time show an average of 0.200 ± 0.01 s, which is comparable to our findings, when the gymnast in all three attempts of particular difficulty element shows contact times 0.213 s, 0.209 s and 0.198 s, respectively. The Italian gymnast's average length of the flight phase (0.500 ± 0.01 s) is exactly the identical as of the Slovakian gymnast (0.500 s).

The most comparable results are found in the study of Purenović et. al. (2010) who followed a similar element (*split leap with the trunk bended backward, and one leg implied in the take-off, after the running*). Due to fact that in our research we only investigated the temporal variables of the CoM, we can only compare the duration of the flight phase. The obtained research results showed the longer duration of the flight phase (0.57 s) to the values achieved in this study (0.50 s).

Logically, greater flight time gives a greater opportunity for the gymnast to establish required form of the body during the flight phase. During this phase, a gymnast reaches a necessary shape at first, and then prepares for landing. Duration of the shape depends on the duration of the flight and the time taken to reach the shape evaluated by judges. The time to reach the form can only be reduced by increasing the velocity of the center of mass at the take-off (Jastrjembskaia & Titov, 1998).

Vertical potential of rhythmic gymnasts has been measured also by Gateva (2014). The findings showed the average jump height of Bulgarian gymnasts 37.4 ± 4.2 cm, with maximum 53.0 cm and minimum 32.0 cm. Our gymnast´s values show similarity, with the average jump height 39.7 cm, calculated from 3 attempts in vertical counter-movement jump with the fixation of the arms.

CONCLUSIONS

Biomechanical considerations as reflected in correct or incorrect technique, particularly in RG as well as others gymnastic disciplines are more than undoubted. This case study focused on kinematic analysis of the Stag leap with back bend of the trunk, and simultaneously on the explosive power of lower limbs regarding this particular RG difficulty element. In the study biomechanical analyse was presented on basis of the results of one subject. Although the gymnast was a top level she didn´t meet the minimum FIG requirement for the recognition of the element value (the range between legs of at least 180°), and reached only160°. On the other hand, CoM height in the flight phase has been considered as "above average" (40.8 cm), and had an impact on the correct overall execution (e.g. symmetrical shoulder position, maximum knee flexion of the anterior leg and maximum knee extension of the posterior leg). We assume that the CoM height in the flight phase of gymnast was positively influenced by her output in the active take-off phase (52.8 $W.kg^{-1}$) mostly. Based on the results of kinematic 3D analysis and diagnostics of the explosive force of the lower limbs, we especially recommend to include plyometric exercises to the training 3 times per week and combine them with the coordination exercises that correspond to physical activity in specific jumps of RG, as they focus on active reflection and the use of elastic energy.

Despite the limitation of this study (e.g. one gymnast only, which caused not enough measurements for the statistical analyse) we can conclude that the evaluation of the kinematic characteristics by 3D analysis is a very exceptional way to identify the errors in the execution of the specific difficulty element, as well as the key phases. Additionally, our finding demonstrates the significance of the explosive power of the lower limbs in rhythmic gymnastics. This information could help in practice to design and organise specific training, to evaluate the training stimuli with the aim to minimize errors and maximize effectiveness. However, to understand this issue better, it is necessary to conduct the studies with a wider sample of top-level rhythmic gymnasts preferably within the competition conditions.

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