KINETIC AND KINEMATIC ANALYSIS OF THREE DIFFERENT EXECUTION MODES OF STAG LEAP WITH AND WITHOUT THROW- CATCH BALL IN RHYTHMIC GYMNASTICS

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Abstract

Visual analysis of rhythmic gymnastics shows that the greatest difficulty lies in jumps. Performing jump with optimal speed, great amplitude, and better coordination and without any mistakes, does not depend only on the gymnast's capacity but also on the apparatus used, the jump made and the applied momentum. The objective was to study the qualities of strength, speed and flexibility developed during the three execution modes of stag leap with ring with and without throw-catch ball. Seven gymnasts from the national rhythmic gymnastics team aged between 15 to 21 years participated in this study. The protocol in making three stag leaps with rings consist of the following: the first without apparatus, the second with throwing ball during the chasse step, and the third with throwing ball at the time of pulse during stag leap with ring. The basic descriptive parameters and statistical significance of differences were determined by using the SPSS 20.0, statistical program for data processing. The results show a significant variation at $p < 0.05$ in the execution factors when introducing apparatus such as, horizontal and vertical velocity, right knee angle, force, horizontal displacement of toe, the angular momentum of the centre of mass and angular velocity of right leg. This decrease differs according to the moment of throwing the ball. In conclusion, we can argue that introducing ball during the chasse step causes a change in the basic performance factors.

Keywords: *kinetic, kinematic, stag leap, chasse step, throw-catch ball.*

INTRODUCTION

Rhythmic gymnastics (GR) is an exclusively female Olympic sport that involves performing exercises with musical accompaniment. When a gymnast performs her competition routine, she coordinates her body movement with handling an apparatus, such as ball, hoops, ropes, ribbons and clubs (Sierra-Palmeiro, Bobo-Arce, Pérez-Ferreirós, & Fernández-Villarino, 2019), according to the code of points FIG (2017-2020) the gymnast must include only elements that can be performed safely and with high degree of aesthetic and technical proficiency. There are four

difficulties components: Body Difficulty (BD), dance steps combination (S), dynamic elements with rotation (R), and apparatus difficulty (AD). BD elements are elements from the difficulty tables in the code of points FIG (2017-2020), and it is divided into three groups: leaps/jumps; balances and rotations.

According to Gantcheva, Mineva, Locquet, and Léziart (2008), gymnasts choose 34.61% BD of jump prescribed by the code of points, and it's the most globally exploited group. Polat (2018) defined RG as a high leap demanding, Hutchinson, Tremain, Christiansen, and Beitzel (1998) defined jumps as a fundamental movement that requires complex motor coordination of the upper and lower limbs, on the other hands, they have seen them an essential component in RG performance. All the difficulties of jumps/leaps must have a defined and fixed shape during the flight and height (elevation) of the jumps that is sufficient to show the corresponding shape since if the jump shape is not fixed and defined, it will not be valid, and this depends on the diverse elements; such as muscular strength, explosive power body build, muscular speed, elasticity and motor coordination (Çimen, 2012). Ttherefore, to be able to execute the jumps with this amplitude, it requires a fairly high speed of execution which needs some strength potential in order to accelerate or flourish the gymnast's own body. Also, it is necessary to achieve a level of automation and a very high gestural coordination to be able to coordinate between the jump and the work of the selected apparatus.

BD are valid when performed with a minimum of 1 fundamental apparatus technical element specific to each apparatus and/or without fundamental apparatus technical element, for the jumps they are mostly in connection with throwing apparatus, throwing is valid, if the apparatus is thrown at the beginning, during or towards the end of the difficulty, and with catch, if the apparatus is caught at the beginning during or towards the end of difficulty (FIG, 2017-2020).

Regarding the technical aspects, according to Bobo-Arce and Méndez-Rial (2013) jumps are the skills mostly studied, from where many studies analyzed several aspects of the jump. The study conducted by Purenović, Bubanj, Popović, Stanković, and Bubanj (2010) determined the difference in the certain kinematics parameters, between two types of the leap, the front split leap with the trunk bended backward and both legs implied in the takeoff after the running. Another study that evaluated the variation of execution factors, is when performing gymnastics jumps split leap with and without throw catch of the ball (Mkaouer, Amara, & Tabka, 2012). The study conducted by Miletić, Katić, and Maleš (2004) established the probable influence of the characteristic motor's ability and skill factors on the jumping/leaping performance. Another two studies conducted by (Sousa & Lebre, 1996, 1998): the first analyzed the different techniques used by the gymnast to perform two jumps: the leap jump, and the leap jump with trunk extension, and the second, analyzed the fundamental kinematic parameters and the technique used in RG to perform four different jumps. The published study of Polat (2018) examined and compared the parameters of leaps executed with two different take offs on split leap and stag leap with ring, the first take off from 1 foot and the second take off from 2 feet.

Up to date in biomechanical literature, they have compared several jumps with stretch and/or bent legs with and without apparatus, but there is no existence of any study that compared the differences between throwing during the take-off and throwing during jump.

As a result, strength, speed, flexibility and coordination have an important role on rhythmic gymnastics performance's capability. In this regard, we propose to study, in this research, the qualities of strength, speed and flexibility developed during the three modes of execution of the

stag leap with ring, the first without apparatus, the second with throw-catch of ball on take-off, and the third with throw-catch of ball on jumps. We will focus primarily on the degree of deployment of the execution factors with a special attention on the quality of execution, and in order to provide athletes and coaches feedback for better choices to the technique used since they have the same values.

METHODS

Seven volunteer rhythmic gymnasts from the Tunisian senior national team (age 18.71 ± 2.69 years; height 1.67 ± 0.04 m; weight 58.43 ± 4.03 kg) (table1); (average training 20h/week) agreed to participate in this study. The subjects were in good health, without muscular, neurological or tendon injury. After being informed in advance with the procedures, methods, benefits, and possible risks of the study, each participant had to review and sign a consent form to participate in the study. The experimental protocol was performed in accordance with the Declaration of Helsinki for human experimentation (Carlson, Boyd, & Webb, 2004) and was approved by the local Ethical Committee.

The kinetic and kinematic study was performed at the Higher Institute of Sport and Physical Education of Ksar-Saïd (ISSEP Ksar Said), on an evolution mat wherein is integrated a force plate (Kistler Quattro Jump, type: 9290AD, ref. 2822A1-1, sampling frequency 500 Hz). It is a two-dimension "2D" study based on a reference (ox; oy). The stag leap with ring sequences were recorded using two cameras (50 Hz; Sony DCR-PC108E Mini DV, 1 million pixels CCD and Shutter speed, 1/4000th of a second) with wide conversion lens (0.6x; 45.5 by 29 mm). Body markers using the Hanavan model (Hanavan, 1964) modified by De Leva (1996) were digitized using the video-based data analysis system SkillSpector® 1.3.2 (Brønd, 2009) (Odense SØ – Denmark) with quantic-spline data filtering. The body segments' centres of mass (COM) were computed using the de Leva (1996) model. The video acquisition is accomplished through the FireWire bus (iLink / IEEE 1394), in full frame without compression. The construction of key positions and 3D kinogramme is developed by Curious Labs, Inc. Poser® Software 4.0.3 (Figure 1).

The gymnast is placed on the mat in front of the two cameras, one facing 5 m from the mat and the other in profile 3 m from the axis of movement. The gymnast wears 20 reflective markers glued to her body; she performs a momentum in the form of chasse step (Figure 2) while trying to be placed on force plate during the impulse to perform the stag leap with ring.

Before the event, each gymnast performs the jump 3 times trying to calibrate its evolution to make the jump on force plate. It is a dual kinematic and dynamic approach, carried out over 3 days from 14 to 16 o'clock. The video acquisition is synchronized with the force platform through a mechanical system. Each gymnast, after a free warm-up of 15 min, is called to make three different jumps: arm straight (a) Chasse Step + Stag Leap with ring Without Ball (CS SL WB): The gymnast standing up, the body straight, feet tight on the half-point. She makes a chasse step followed by an elevation of the free leg flexed forward with attachment of the thigh to the horizontal, this action is followed by an elevation of the back leg support in ring and also with a good fixing of the shape in order to achieve a stag leap with ring (Figure 2); (b) Throw the Ball during the Chasse Step + Stag Leap with ring (TB CS SL): the gymnast standing up with a ball in her hand, the body straight, feet tight on the half-point, she swings her hand backwards to take the momentum of throw, she throws the ball during the chasse step with arm straight and catches it during the stag leap with ring without making technical mistakes (Figure 3); (c) Chasse Step + Throwing Ball during the Stag Leap with ring (CS TB SL): the gymnast standing up with a ball in her hand, the body straight,

feet tight on the half-point, She takes a chasse step with swinging her arms backwards to throw the ball during the stag leap with ring with arm straight and catches it during reception without making technical mistakes (Figure 4).

Table 1
Descriptive statistics of anthropometric measurements.

	Min	Max	Mean	SD
Weight (kg)	54	65	58.43	4.03
Height (m)	1.62	1.74	1.67	0.04
Age	16	21	18.86	2.03
Years of practice	11	15	12.14	1.95

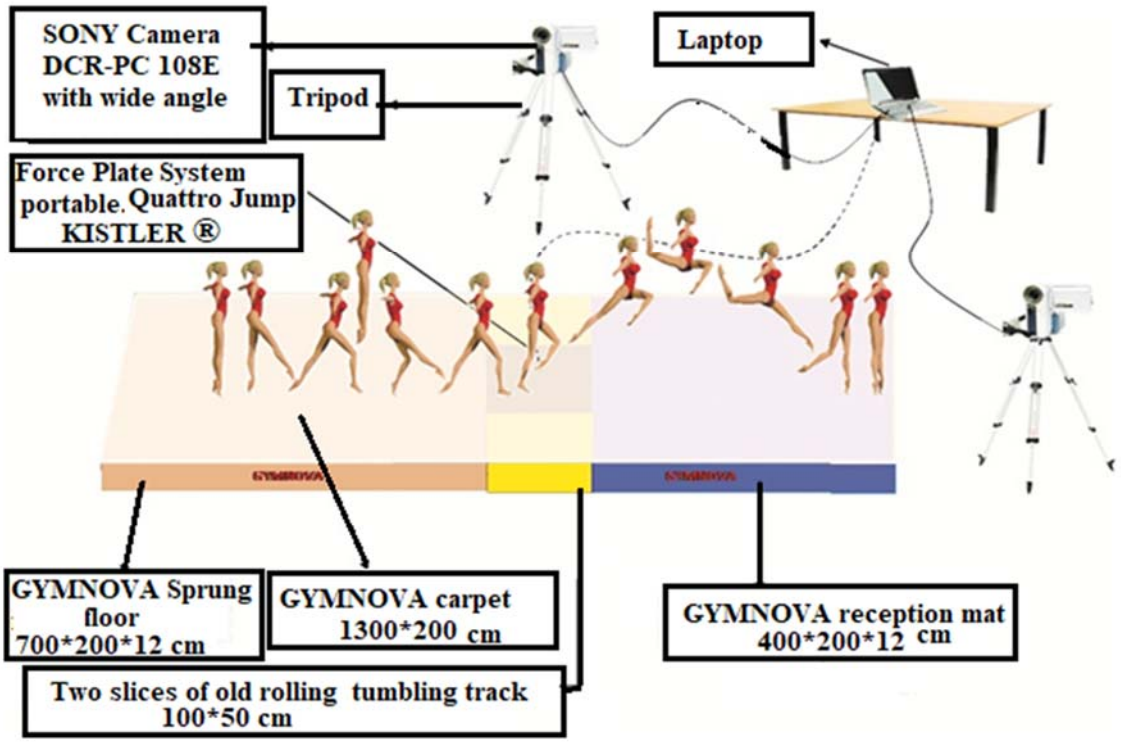

Figure 1. Experimental device.

Figure 2. Chasse step stag leap with ring without throw-catch of the ball.

Figure 3. Throwing ball during the chasse step.

Figure 4. Throwing ball during the stag leap with ring.

A	B	C
B	C	A
C	A	B

Figure 5. Randomized protocol, Latin Square (Zar, 1984).

Each jump is performed three times [randomized protocol, Latin Square Zar (1984), (Figure 3)], with a recovery of 2 minutes between repetitions. Two international judges evaluate the exercises, based on the code of point FIG (2017-2020). The best evolution of each gymnast was chosen for the comparative study.

Data are reported as mean ± standard deviation (SD). Effect size (*dz*) was calculated using GPower™ software [Bonn FRG, Bonn University, Department of Psychology (Erdfelder, Buchner, Faul, & Brandt, 2004)]. The following scale was used for the interpretation of dz: < 0.2, [trivial]; 0.2<0.6, [small]; 0.6<1.2, [moderate]; 1.2<2.0, [large]; and >2.0, [very large] (Scanlan, Dascombe, & Reaburn, 2012). The normality of distribution estimated by the Kolmogorov-Smirnov test was acceptable for all variables. Therefore, ANOVA with repeated measures was applied to compare different stag leap with ring, Bonferroni test was applied to pair wise comparisons. The results were considered significantly different when the probability was less than or equal to 0.05 ($p \leq 0.05$). Statistical analyses were performed using the software package SPSS version 20.0 [SPSS, Chicago, IL, USA].

RESULTS

The results are considered significantly different when the probability is less or equal to $p \leq 0.05$, performance factors when the stag leap with ring is executed without apparatus (CS SL WB) ware significantly different from those when stag leap with ring is executed with throw-catch of the ball on the chasse step (TB CS SL) or on the stag leap with ring (CS TB SL) (table 2).

Table 2 shows the univariate analysis of CS SL WB, TB CS SL and CS TB SL. These were compared between the three modes and presented in table 3.

Bonferroni post hoc test demonstrated that the three modes had different effect on the execution factors of the stag leap. The horizontal velocity of the COM (Vx_{COM}) decreased when throwing ball on the chasse step (CS SL WB Δ TB CS SL = 17.25 % with $p \leq 0.05$). On the other hand, the vertical velocity of the COM (Vy_{COM}) decreased when throwing ball on the stag leap (CS SL WB Δ CS TB SL = 13.27 % with $p \leq 0.05$).

Indeed, we noticed a drop of the angular momentum of the COM (Ma_{COM}) when throwing ball on the chasse step (CS SL WB Δ TB CS SL = -82.56% with $p \leq 0.05$).

Alternatively, the horizontal displacement of the COM (dx_{COM}) decreased when throwing ball on the chasse step and also on the stag leap with ring (CS SL WB Δ TB CS SL = 25.19 % with $p \leq 0.05$ and CS SL WB Δ CS TB SL = 19.66 % with $p \leq 0.05$).

Similarly, the horizontal displacement of the toe (dx_{toe}) decreased during the two techniques with throw−catch of ball (CS SL WB Δ TB CS SL = 18.83 % with $p \leq 0.05$ and CS SL WB Δ CS TB SL = 1.42 % with $p \leq 0.05$).

Table 2
ANOVA repeated measure. Univariate analysis of three modes execution of the stag leap with ring.

	df	Mean Square	D	Sig.	Effect Size (*dz*)	Power
COM Horizontal Velocity Vx_{COM} (m/s)	2	0.177	4.980	0.027	1.823	0.700
COM Vertical Velocity Vy_{COM} (m/s)	1.061	0.422	7.351	0.032	2.215	0.642

COM Horizontal Displacement dx_{COM} (m)	2	0.074	10.011	0.003	2.582	0.948
Horizontal Displacement of toe dx_{toe} (m)	2	0.085	8.966	0.004	2.444	0.923
COM Angular Momentum Ma_{COM} (kgm^2/s)	2	93905.086	4.763	0.030	1.783	0.679

Table 3
Post Hoc comparative study between the three modes of stag leap with ring execution.

		Mean ± SD	Mean Difference	Standard Error	Sig.	Effect Size (*dz*)
Vx_{COM} (m/s)	CS SL WB	1.837 ± 0.126	0.317	0.088	0.034	3.602
	vs TB CS SL	1.520 ± 0.224				
Vy_{COM} (m/s)	CS SL WB	2.449 ± 0.209	0.326	0.034	0.000	9.588
	vs CS TB SL	2.124 ± 0.237				
Ma_{COM} (kgm^2/s)	CS SL WB	-41.767 ± 84.171	197.742	58.743	0.045	3.366
	vs TB CS SL	-239.509 ± 194.205				
dx_{COM} (m)	CS SL WB	0.778 ± 0.142	0.195	0.042	0.011	0.464
	vs TB CS SL	0.582 ± 0.184				
	CS SL WB	0.778 ± 0.142	0.152	0.043	0.035	0.353
	vs CS TB SL	0.625 ± 0.117				
dx_{toe} (m)	CS SL WB	1.051± 0.187	0.199	0.051	0.025	3.901
	vs TB CS SL	0.853 ± 0.166				
	CS SL WB	1.051± 0.187	-0.183	0.054	0.045	0.294
	vs CS TB SL	1.036 ± 0.114				

(COM) Centre of mass; (Vx) Horizontal Velocity; (Vy) Vertical Velocity;(Ma) Angular Momentum; (dx) Horizontal Displacement; (dx toe) Horizontal Displacement of the toe; (CS SL WB) chasse step and stag leap without ball;(TB CS SL) Throw the ball during the chasse step and stag leap with ring; (CS TB SL) chasse step and throwing ball during the stag leap with ring.

DISCUSSION

The purpose of the present study was not only to examine the effect of introducing ball on the execution factors of stag leap with ring, but also to study which of the two techniques with apparatus allows a perfect execution of the jump, form where, kinetic and kinematic analysis show a difference in the degree of deployment of qualities speed and of displacement of the COM.

Vertical velocity achieved by our gymnasts shows a significant difference between the technique without ball and with throwing ball during the stag leap with ring with a favour to the technique without apparatus. This drop can be explained by blocking the arms actions during the jump with throwing (CS TB SL). According to Rutkowska-Kucharska (1998) the arm swing caused a statistically increase in height in all kinds of jumps and since the amplitudes of displacement of the COM are on average more important at fast speed than at slow speed (Grandjean, Paparemborde, & Baron, 1985). Therefore, there is a positive correlation between the height (i.e., vertical displacement) and the vertical speed. This means that to have a higher vertical speed it is necessary to add the arms swinging from where the fall of the speed during the blocking of the arms on the techniques of throwing the ball during the

jump. Since, this jump is realized with two legs flexes which requires better attention, while without apparatus, gymnast performs an asymmetrical movement of the arms to adjust her posture which increase the vertical velocity. This is different to the work of Mkaouer et al. (2012) who determined a significant difference but with a favour to the jump with throw-catch of ball, who explained this raise by the arm action when throwing while the speed of slit of the legs, since this jump is realized with two legs stretched, which explains the difference between two jumps. Also, stag leap with ring and split leap differs greatly in their biomechanical model, the first is mainly vertical jump while the second is a horizontal leap. According to these results, the vertical speed of LB CS SL is better than CS TB SL, which can be explained by the fact that in the first technique the gymnast has the free hand so she can swing her arms, in accordance to Feltner, Bishop, and Perez (2004) and Harman, Rosenstein, Frykman, and Rosenstein (1990) which showed that vertical jump was significantly larger in the arm swing jumps compared to the no arm swing jumps and was due to a larger vertical velocity of the COM.

In addition, horizontal velocity shows also a significant difference between CS SL WB, with a drop when throwing ball, which conformed by the work of Mkaouer et al. (2012). This decrease can be explained by the fact that the gymnast throws the apparatus during the chasse step where it is necessary to adjust its position to be able to catch ball without execution errors. The tested gymnasts developed a horizontal velocity fairly low compared to the stag leap, this difference can be explained by the type of jump made since the split leap according to Sousa and Lebre (1998), is classified among the jump that have a high horizontal speed, while the stag leap with ring is classified among the jumps that have a low horizontal velocity.

This decrease can be explained by the blocking of the arms action during the jump with apparatus. Without apparatus, the gymnast performs an asymmetrical movement of the arms to accelerate, while with a throw of the ball and especially when the apparatus is thrown during the jump. The gymnast cannot perform this movement to ensure the gesture with a good height and correct direction.

The horizontal displacement of the toe (dx_{toe}) and COM (dx_{COM}) from the beginning to the end of the jump shows a significant difference between CS SL WB versus TB CS SL and between TB CS SL versus CS TB SL, almost similar to that found by Sousa and Lebre (1998) during a single stag leap with ring. In this respect, the analysis of the obtained results allows us to notice that the technique without apparatus (i.e., CS SL WB) make a greater horizontal displacement than those with ball (i.e., TB CS SL and CS TB SL), which can be explained by the introduction of a second task “throw / catch” of the ball, since the gymnast in these two techniques will adjust her body position to catch the apparatus, knowing that she does not have the right to realize an additional steps for catching ball. That's why we find a decrease in the distance travelled during the two techniques with apparatus.

Angular momentum of the COM (Ma_{COM}) shows also a significant difference between CS SL WB versus TB CS SL (Ma_{COM} = -41,767 Vs -239,509 kgm^2/s respectively). This decline according to Pascal (2003), can be explained by the fact that the kinetic moment can only be changed if a new external force is applied on the body; in other words, only the phases where we are in contact with the ground or tackle allow us to maintain or change the kinetic moment of the body. This notion is fundamental since the drop was introduced when the ball is thrown during the chasse step so the gymnast must bring her arm forward to catch the ball instead of placing it next to her ear.

CONCLUSIONS

The results of this study have shown that the technique without apparatus (CS SL WB) is the best compared to the two other techniques in economy of effort, particularly in terms of vertical and horizontal velocity, horizontal displacement of the toe and of the COM and of the angular momentum of the COM in regards to the technique with apparatus, the values undergo a decrease which differs according to the moment of throwing of the ball, "to throw during the chasse step (TB CS SL) or to throw during the jump (CS TB SL)". The results showed that the technique with throw during the jump (CS TB SL) proves the best technique compared to the first one (TB CS SL) allowing a better vertical velocity (Vy_{COM}) and an optimal horizontal displacement of toe and COM. In addition, the TB CS SL has only the best horizontal velocity (Vx_{COM}) and angular moment of COM (Ma_{COM}).

In conclusion, we can argue that the technique with throwing ball during the jump (CS TB SL) is the best technique to have a stag leap with ring jump with optimal performance factors.

In light of the results of this study, it is recommended for coaches and gymnasts to work on this technique at the beginning without ball, in order to improve it, and on the exercise they should choose the technique with throwing during the jumps since they have the same value according to the code of points (FIG, 2017-2020).

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