

EFFECT OF ASSEMBLÉ-STEP ON KINETIC AND KINEMATIC PARAMETERS OF STAG RING LEAPS WITH AND WITHOUT THROW-CATCH OF THE BALL IN RHYTHMIC GYMNASTICS

Hounaida Akkari-Ghazouani^{1,2}, Samiha Amara^{1,3}, Monem Jemni⁴,
Mokhtar Chtara^{1,2}, Bessem Mkaouer²

¹ Tunisian Research Laboratory “Sport Performance Optimization”, National Centre of Medicine and Science in Sport, Tunisia

² High Institute of Sport and Physical Education of Ksar Said, Manouba University, Tunisia

³ Department of Physical Education and Sport Sciences, College of Education, Sultan Qaboos University, Sultanate of Oman

⁴ Hartpury University, UK

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Abstract

This study was conducted to compare the kinetic and kinematic factors of stag ring leap with and without throwing the ball using the two-leg take-off ballet-step “Assemblé” between three different modes in rhythmic gymnastics (RG). Seven members of the Tunisian RG national team (age 18.71 ± 2.69 years; height 1.67 ± 0.04 m; weight 58.43 ± 4.03 kg) took part in this study. A kinetic and kinematic analysis of three stag ring leap execution modes (i.e., assemblé stag ring leap without ball, throw ball assemblé stag ring leap and assemblé throw ball stag ring leap) using two cameras on a specially designed floor carpet where a force plate was integrated was conducted. The result showed that the vertical component of force, the rate of force development, the angle of split legs and the horizontal and vertical velocity were significantly different ($P < 0.01$). In this study, it was found that while performing the stag ring leap element, gymnasts present the highest value in both kinetic and kinematic parameters when throwing the ball during the jump (i.e., assemblé throw ball stag ring leap). In light of the obtained results, it is recommended that coaches start working with gymnasts on the throws during the jump from their youngest age, as this could help them attain the optimal performances in competition.

Keywords: Leap, Run-up, Take-offs, Apparatus.

INTRODUCTION

Rhythmic gymnastics is defined as an aesthetic purely feminine Olympic sport performed in harmony with musical accompaniment (Akkari-Ghazouani, Mkaouer, Amara, & Chtara, 2020; Bobo-Arce & Méndez Rial, 2013; Chiat & Ying, 2012; Coppola, Albano, Sivoccia, &

Vastola, 2020; dos Reis Furtado, de Toledo, Antualpa, & Carbinatto, 2020; Douda, Toubekis, Avloniti, & Tokmakidis, 2008; Putra, Soenyoto, Darmawan, & Irsyada, 2020; Selecká, Krnáčová, & Lamošová, 2020). Gymnasts are awarded scores which are based on a Code of Points

governed by the International Gymnastic Federation (FIG, 2020) and updated every four years.

RG exercises are evaluated by two groups of judges: difficulty (D) and execution (E), under Strand D. They are evaluated on body difficulties (BD) (i.e., jumps, balance, and rotation), dance steps combinations (S), apparatus difficulties (AD) and dynamic elements with rotation (R). They are evaluated on technical and artistic performances (FIG, 2020).

In order to be able to successfully execute her exercise, the gymnast must first work on the essential basic qualities that allow her to successfully execute the different parts of her exercise. We can mention velocity, strength, flexibility, and coordination as the determinant qualities of performance in RG (Abd El-Hamid, 2010; Akkari-Ghazouani et al., 2020; Ashby & Heegaard, 2002; Coppola et al., 2020; Douda et al., 2008; Selecká et al., 2020). Therefore, for better execution of difficulties (i.e., jumps, balances, and rotations), the gymnast should develop these qualities. However, among the body difficulties groups, many studies indicated that the jumps group was the most important and the most studied (Akkari-Ghazouani et al., 2020; Hutchinson, Tremain, Christiansen, & Beitzel, 1998; Kums, Ereline, Gapeyeva, & Paasuke, 2005; Mkaouer, Amara, & Tabka, 2012; Polat, 2018; Purenović, Bubanj, Popović, Stanković, & Bubanj, 2010; Sekuli, Cacute, & Wolf-Cvitak, 2004; Sousa & Lebre, 1996, 1998).

The take-off is the key moment in gymnastics' performance, and it is therefore of interest to coaches and gymnasts who want to specifically improve their jump performances. According to Selecká et al. (2020), the four phases (i.e., preparatory phase, take-off phase, flight phase and landing) must be performed fluently. This would mean that a good start (preparatory phase) allows a good jump. However, the chasse step is the most studied in the literature. It allows a

one-leg take-off (Akkari-ghazouani et al., 2020; Coppola et al., 2020). Since the type of the run-up step used during the preparatory phase has no effect on the starting score of the gymnast, making a jump with only one leg or two legs during the take-off does not change anything in the score. Therefore, it is necessary that she chooses the best run-up step which allows her to execute her difficulty. This leads to the idea of analysing the only run-up step that enables two legs on take-off, something called the *assemblé*. The latter has been studied as a preparatory phase for a front split-leap with the trunk bent backward (Purenović et al., 2010), with a split-leap (Polat, 2018), with stag-leap and back bent (Selecká et al., 2020), and with the stag ring leap without apparatus. Likewise, the throw of the apparatus at the beginning, in the middle or at the end of the jump does not change anything in the score. The only rule imposed by the Code of Points (FIG, 2020) is to make a big throw. This leads us to analyse this technique with two different moments of the throw in order to distinguish the best moment in it to perform a jump with optimal execution factors.

Among the most important leaps that must be acquired by the gymnast, we have chosen the stag ring leap, which is considered one of the fundamental gymnastics skills, and a key movement in the development of elite female gymnasts (Nabanete dos Reis Furtado, de Toledo, Fernandes Antualpa, & Carbinatto, 2020; Selecká et al., 2020).

The aim of this research was to analyse the effect of introducing the ball on the realisation of a stag ring leap, and to determine which of the two techniques allows to have a better jump. We hypothesized that the introduction of the ball might change the performance of the stag ring leap. We also hypothesized a probable increase in jump performance factors when throwing during the jump (i.e., *assemblé* throw ball stag ring leap) since the throw is made during the take-

off. Such changes would not be observed for the technique of throwing before the jump (i.e., throw ball assemblé stag ring leap).

METHODS

A minimum sample size of 7 participants was determined from an a priori statistical power analysis using G*Power software [version 3.1 University of Dusseldorf, Germany (Faul et al., 2009)]. The power analysis was computed with an assumed power of 0.95 at an alpha level of 0.05 and a moderate effect size of 0.8. Therefore, seven senior rhythmic gymnasts from the Tunisian National Team Senior ($n=7$; age 18.71 ± 2.69 years; height 1.67 ± 0.04 m; body mass 58.43 ± 4.03 kg; training average 20h/week; years of practice 10.57 ± 1.84 years and years of practice on the national team 6.71 ± 1.27 years) took part in this study. All participants were in good health, without muscular, neurological or tendon injury. After being informed in advance of the procedures, methods, benefits, and possible risks of the study, each participant and/or parent/legal representatives of gymnast (i.e., for gymnasts under 18) reviewed and signed 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 Ethical Committee of the National Centre of Medicine and Science in Sport (LR09SEP01).

The overall idea of this study was to determine the best way to better perform the jumps through improving their phases (Selecká et al., 2020). The specific aim of this research was to scrutinise and compare the kinetic and kinematic factors of stag ring leap using two types of throws: The first is with and without throwing during the run-up step (ASWB Vs TBAS); and the second is with and without throwing the ball during the jump at take-off

(ASWB Vs ATBS). These techniques were carried out using the two-leg take-off ballet-step "Assemblé". To our knowledge, this technical combination (i.e., assemblé-step / stag ring leap with and without two types of throwing apparatus) has never been studied/analysed in rhythmic gymnastics.

Before performing the test, every gymnast undertook a 10-min warmup which included specific exercises for flexibility of the lower limbs (static hamstring and split exercise) and the trunk (wheel variations and lumbar mobility). Afterwards, they were allowed to trial the jump 3 times (with a 2-min rest between repetitions) whilst adjusting to making the take-offs on the force-plate. The design of the study was a double-acting approach "kinematic and kinetic", undertaken over 3-days from 14:00 to 16:00 o'clock. The video acquisition is synchronized with the force-plate through the time code "TC-Link".

The experiment was performed on a gymnastics carpet, in which we integrated a force-plate [Kistler Quattro Jump, type: 9290AD, ref. 2822A11, sampling frequency 500 Hz]. Thereafter, each gymnast was called to randomly perform three modes of execution of stag ring leap with and without throw-catch of ball using the assemble-step for the take-off with two legs:

(a) Assemblé stag ring leap without ball [ASWB] (Figure 1a): The gymnast stood in a straight body position with both feet together. She made a step in which the working foot slid on the ground before being swept into the air; as the foot went into the air the dancer pushed off the floor with the supporting leg, extending the toes. Both legs came to the ground simultaneously in the fifth position (ABT, 2006). Then she pushed up from the floor with two legs; when mid-air, she pulled one leg flexed forward and the other flexed behind.

The arms must move with the jump to propel the jump higher to land. She then pulled legs back into the original position and landed gently back to a straight body position.

(b) Throwing ball on the assemblé (i.e., in the run-up phase) and catch it on the stag ring leap (i.e., in the landing phase) [TBAS] (Figure 1b): In this second technique, the gymnast should throw the ball on the assemblé and catch it on the stag ring leap.

(c) Assemblé and throw ball on the stag ring leap jumping phase and catch on the landing phase [ATBS] (Figure 1c): In this last technique, the gymnast should throw the ball in the technical element (i.e., in the take-off phase) and catch it at the end of the jump (i.e., in the landing phase) using the assemblé as a run-up step for the take-offs.

For each technique, the gymnast performed three trials [randomized protocol, Latin Square (Zar, 1984)], with 2-minute recovery between repetitions, supervised by two international judges. The best performance selected by the judges was chosen to be used in the comparative study. The only advice to the participants was to make the take-off on the force-plate. The execution was neither limited by a time nor imposed rules.

To record the skill, two Sony DCR PC105^E cameras [1-megapixel CCD, 50 fps, 1 Lux minimum sensitivity] with wide conversion lens were used. They were positioned to capture the entire movement of the experience. The first was on the frontal plane 5m from the mat and the second was on the sagittal plane 3m from the mat. Passive markers were taped to each gymnast to carry out the kinematic analysis on the basis of the Hanavan model (Hanavan & Ernest, 1964) modified by De Leva (1996). This basic model includes 20 points and 14 segments distributed throughout the body. Data digitalization

was realized via a video-based motion and skill analysis system, SkillSpector® [Version 1.3.2, Odense SØ – Denmark] (Brønd & Elbæk, 2013) with quantic-spline data filtering. The video acquisition was achieved with the FireWire bus [iLink / IEEE 1394], in full frame without compression. The construction of key positions and 2D kinograms was developed by Adobe Illustration© [1987-2019 Adobe].

Maximal vertical force (F_y) and maximal rate of force development (RFD) of the stag ring leap take-offs were analysed via direct kinetic data, and the centre of mass' displacement (dx_{COM} and dy_{COM}) and velocity (Vx_{COM} and Vy_{COM}) were analysed via manual digitized kinematic data. The angular data of the angle of split legs ($AngS_{leg}$) during the stag ring leap were also analysed.

Statistical analysis was conducted via SPSS 20.0 software [SPSS. Chicago. IL. USA]. Descriptive statistics (means $\pm$ SD) were performed for all variables. The effect size (d) was conducted using G*PowerTM software [Version 3.1, University of Dusseldorf, Germany (Faul, Erdfelder, Buchner, & Lang, 2009)]. The following scale was used for the interpretation of d : < 0.2 , trivial; $0.2 - 0.6$, small; $0.6 - 1.2$, moderate; $1.2 - 2.0$, large; and > 2.0 , very large (Hopkins, 2002). The normality of distribution estimated by the Kolmogorov-Smirnov test was acceptable for all variables ($p > 0.05$). Consequently, a one-way ANOVA with repeated measures was used for all variables (kinetic and kinematic) to benchmark different stag ring leaps. The Bonferroni test was applied in post-hoc analysis for pairwise comparisons. Additionally, effect sizes (d) were determined from ANOVA output by converting partial eta-squared to Cohen's d [small = 0.01, medium = 0.06, and large = 0.14 (Cohen, 1988)]. A priori level less than or equal to 0.5% ($p \leq 0.05$) was used as a criterion for significance.

RESULTS

The results of ANOVA repeated measure showed that there is a significant difference, in both kinetic and kinematic parameters, between the three execution modes (i.e., ASWB, TBGS and ATBS). This difference can be related to the introduction of the apparatus, which is a pre-requisite component for RG, and also to the moment of its throwing. There is a significant difference in the execution parameters of stag ring leap ($p < 0.01$) except for the horizontal and vertical displacement of the COM (dx_{COM} , dy_{COM}) which remains almost stable (Table 1).

Pairwise comparison (i.e., Bonferroni post-hoc test) showed that the three execution modes had different effects on the execution factors of the stag ring leap (Table 2). The vertical component of force

(F_y) increases significantly when the ball is introduced ($p < 0.05$), specifically during the technique of throwing at take-off (ATBS Δ ASWB = 44.35%) (Figure 2a). Similarly, for the RFD, which was increased significantly at $p < 0.001$ during both jumps with ball (ATBS Δ ASWB = 77.99%) (Figure 2b). Also, the analysis showed a significant increase ($p < 0.01$) in the horizontal velocity (V_{xCOM}) when introducing the ball (TBAS Δ ASWB = 39.88% and ATBS Δ ASWB = 55.70%) (Figure 2c). On the other side, the vertical velocity (V_{yCOM}) decreases significantly at $p < 0.05$ when the ball is thrown at run-up compared to take-off (TBAS Δ ATBS = -6.67%) (Figure 2c). Finally, for the angle of split legs ($AngS_{leg}$), it was significantly higher ($p < 0.05$) when throwing the ball during the stag ring leap take-off (i.e., ATBS) (Figure 2d).

Table 1

ANOVA repeated measure of the three stag ring leaps execution modes.

	ICC	CV	df	Mean Square	F	Sig.	Effect size (d)	Power
dx_{COM} (m)	0.647	0.150	2	0.006	2.506	0.530	0.544	0.406
dy_{COM} (m)	0.828	0.187	2	0.213	1.680	0.456	0.617	0.161
V_{xCOM} (m/s)	0.514	0.226	2	0.452	27.922	0.001	4.3126	1.000
V_{yCOM} (m/s)	0.661	0.082	2	0.224	8.866	0.004	2.4292	0.920
$AngS_{leg}$ (°)	0.828	0.051	2	406.286	7.371	0.008	2.2156	0.864
F_y (N)	0.580	0.230	2	2705639.955	15.226	0.007	3.1834	0.906
RFD (N/s)	0.583	0.314	2	431969.439	61.918	0.001	6.4385	1.000

(dx_{COM}) Horizontal displacement of the Centre of mass; (dy_{COM}) Vertical displacement of the Centre of mass; (V_{xCOM}) Horizontal velocity of the Centre of mass; (V_{yCOM}) Vertical velocity of the Centre of mass; ($AngS_{leg}$) Angle of split legs; (F_y) Vertical Force; (RFD) Rate of force development.

Table 2

Post-Hoc comparative study between the three stag ring leaps execution modes.

		<i>Mean ± SD</i>		<i>Mean Difference</i>	<i>Standard Error</i>	<i>Sig.</i>	<i>Effect size (d)</i>	<i>Delta variation (Δ%)</i>
V_{XCOM} (m/s)	ASWB vs TBAS	0.885 ± 0.052	1.238 ± 0.056	-0.353	0.054	0.002	6.53	-39.88
	ASWB vs ATBS	0.885 ± 0.052	1.378 ± 0.052	-0.493	0.084	0.003	5.86	-55.70
V_{YCOM} (m/s)	TBAS vs ATBS	2.312 ± 0.63	2.669 ± 0.092	-0.357	0.089	0.021	4.01	-6.67
$AngS_{leg}$ (°)	TBAS vs ATBS	179.571 ± 4.325	194.143 ± 4.372	-14.571	3.618	0.021	4.02	-8.11
F_y (N)	ASWB vs ATBS	1767.429 ± 99.473	2551.321 ± 112.009	-783.893	204.445	0.026	3.83	-44.35
	TBAS vs ATBS	1790.821 ± 80.014	2551.321 ± 112.009	-760.500	188.605	0.021	4.03	-42.46
RFD (N/s)	ASWB vs ATBS	624.685 ± 35.312	1093.152 ± 24.090	-468.467	53.906	0.000	8.69	-74.99
	TBAS vs ATBS	715.623 ± 23.491	1093.152 ± 24.090	-377.529	20.840	0.000	18.11	-52.75

(V_{XCOM}) Horizontal Velocity of the centre of mass; (V_{YCOM}) Vertical velocity of the centre of mass; ($AngS_{leg}$) Angle of split legs; (F_y) Vertical Force; (RFD) Rate of force development; (ASWB) Assemblé and Stag ring Leap Without Ball; (TBAS) Throw Ball during the Assemblé and Stag ring Leap; (ATBS) Assemblé and Throwing Ball during the Stag ring Leap.

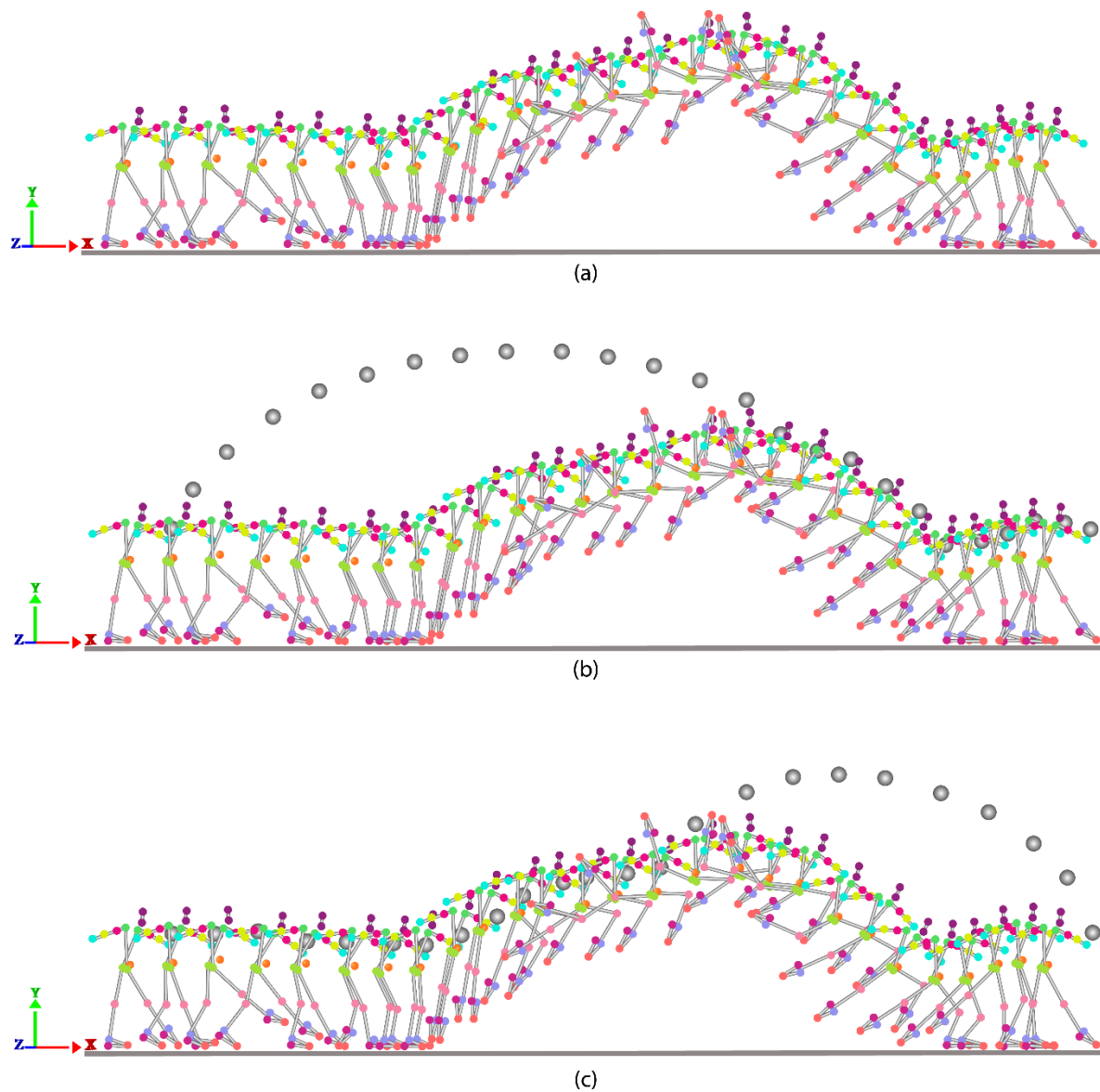


Figure 1. Experimental protocol: (a) Assemblé and stag ring leap without ball (ASWB), (b) Throwing ball during the assemblé and stag ring leap (TBAS), (c) Assemblée and throwing ball during the stag ring leap with ring (ATBS).

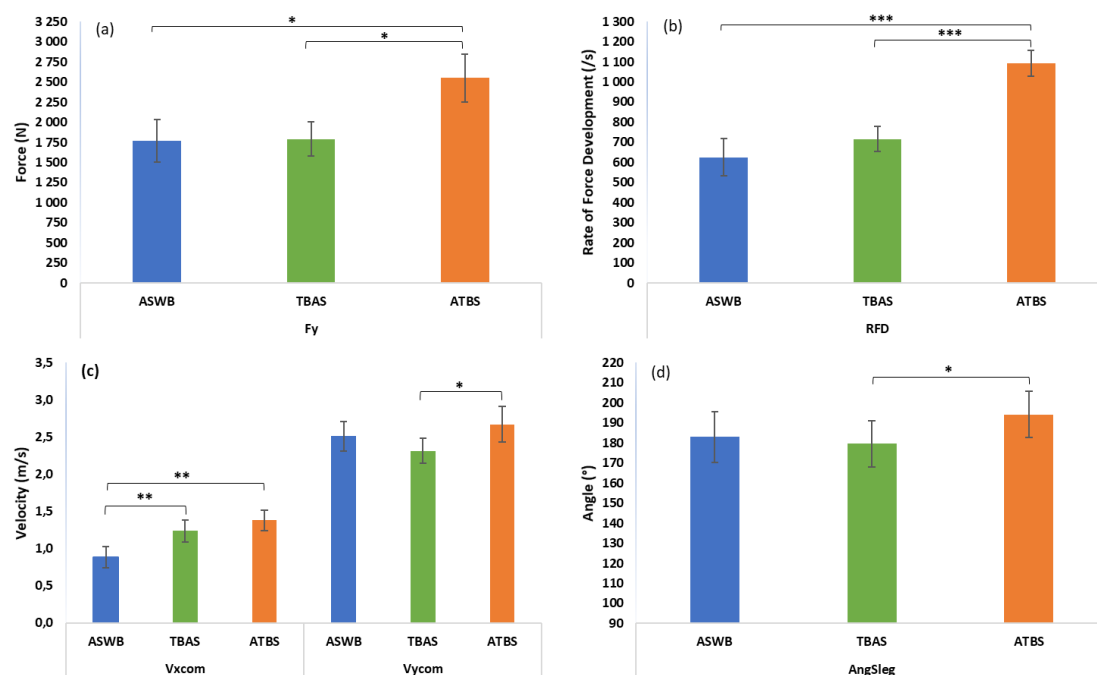


Figure 2. The determinants of performance that varied in the three execution modes of the stag ring leap: (a) Vertical force; (b) Range of force development; (c) vertical and horizontal velocity; (d) Angle of split legs. [(*) significant at $p < 0.05$; (**) Significant at $p < 0.01$; (***) Significant at $p < 0.001$; (ASWB) Assemblé and stag ring leap without ball; (TBAS) Throwing ball during the assemblé and stag ring leap; (ATBS) Assemblée and throwing ball during the stag ring leap with ring].

DISCUSSION

The aim of this study was to investigate the impact of ‘two leg take-off’ using a ballet-step “Assemblé” on kinetic and kinematic parameters of stag ring leap, and also to explore the effect of introducing the ball as well as the best moment for throwing.

The obtained results are significantly different between the three modes, with a higher value with apparatus, especially when throwing the ball during the stag ring leap. Kinetic study showed that the vertical force and the rate of force development varied significantly during the three stag ring leaps. The force is considered as the source of motion (Stone, Stone, & Sands, 2007) and the peak is recorded during the ATBS. This result can be linked to the arms action at take-off. According to several studies, the arms action can

generate a ground reaction force (Mkaouer et al., 2014; Vaverka et al., 2016).

Ratamess (2021) showed that the action of the arms, i.e., their swing, includes an explosive forward and upward movement of the arms with thumbs up. This could explain the difference between ASWB and ATBS. The two stag ring leap modes train with swinging arms, but the ATBS trains with a ball. This could demonstrate that throwing a ball with a vertical arms movement could enhance Fy and RFD. In fact, by throwing the ball, the gymnast stretches her thumbs to ensure the proper direction.

These results are not in accordance with those reported by Mkaouer et al. (2012). They later concluded that the vertical force developed was more important than the jump with apparatus. It could be claimed that the reason for this was that the jump was performed with a

take-off from one foot, while in our research the jump was performed with take-off from two feet, which were in accordance with Bubanj et al. (2010), who stated that the force in the two-legs jump was better than one-leg jump.

An important component to consider when studying jumping ability is the vertical velocity (V_y) (Haguenauer, Legreneur, & Monteil, 2005). Based on the kinematic study, the vertical velocity was higher when throwing the ball compared to the technique without apparatus, with a clear advantage to the ATBS. This result was contradictory to the one found by Akkari-Ghazouani et al. (2020) who analysed the stag ring leap with a one leg take-off using the chasse step. The difference could be explained by the type of take-off made, which confirms that velocity was better when the jumps are executed with both legs take-off compared to one leg take-off (Bubanj et al., 2010; Purenović et al., 2010).

According to Vescovi (2008), when leg movements are coordinated with arm movements, there is an improvement in vertical velocity. On the other hand, with apparatus, the gymnasts present a vertical velocity that is more important during the ATBS than the TBAS, it may be related to the throwing mode of the ball, considering that in the ATBS there is an asymmetrical arms movement, while in the TBAS this action is blocked to give more attention to the ball.

Moreover, the obtained results show that there was a significant change in the horizontal velocity of the stag ring leap performed by elite gymnasts when introducing the ball. Acting on the result, it was shown also that the ATBS is better than TBAS. The results also indicated that whenever vertical velocity increases, the horizontal velocity decreases, which according to Zatsiorsky (2008), can be due to the fact that the jumper pushes forward on the ground during the take-off phase and therefore receives a backward reaction force from the ground.

The development of gymnasts' flexibility, especially the angle of split legs, is among the most important factors of success (Douda, Tokmakidis, & Tsigilis, 2002; Douda et al., 2008; Nelson, Johnson, & Smith, 1983). According to Putra et al. (2020), split jumping (i.e., leap, stag-leap, wall-monkeys, scissors leap) is one of the movements that has beauty, and the appearance of motion that shows the flexibility and flexibility of the joints as wide as possible, especially the hip joint (Batista Santos, Lemos, Lebre, & Avila Carvalho, 2015) which must not be less than 180° in order to count as a valid jump (Putra et al., 2020). Our results showed significant differences between the TBAS and the ATBS, which can be explained by the fact that the moment of action of throwing the ball (i.e., the assemblé-step vs. the take-off phase) influences the stag ring leap. Thus, throwing the ball at the jump (i.e., the take-off phase) helps to increase the time of flight and the execution velocity. This allows the gymnast to have more time to better open her angle of split legs. This result allows us to conclude that throwing the ball during jumps enables a better opening of the legs than during run-ups, and therefore, a more beautiful jump that could have better chances to be highly valued by the judges.

The practice of this run-up step is important for coaches, as it offers a variety of preparatory steps for take-offs with two legs. At the same time, apart from training, it is required to practice the assemblé in exercises by practicing and introducing it in the gymnast's routine. The gymnasts themselves become aware of the fact that take offs with two legs helps achieve a good performance of the jump.

CONCLUSION

The aim of this study was to compare the kinetic and kinematic variables between three stag ring leaps with and without throwing the ball, performed using the assemblé-step as a preparatory phase

for two legs take-off in RG. In light of this research, our hypothesis was confirmed. The introduction of the ball changed the parameters of jump performance. With apparatus, it was better to throw it during the jump than to throw it before (i.e., at the run-up). Choosing the ATBS could be considered the optimal technique in the economy of effort, enabling higher values in both kinetic and kinematic parameters (i.e., force, velocity, and flexibility). The findings of the present study could improve the evolution of the preparatory phase while varying the take-off steps, which subsequently could lead to better jumps with better execution on the technical and aesthetic sides. Coaches should therefore be familiar with the biomechanical analysis of jumps to apply it in practice and to improve performance.

Finally, this study has some limitations related to the analysis system used. It would be better to use a triaxial force-plate and a real-time motion analysis system in future studies.

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Corresponding author:

Dr. Bessem Mkaouer
Individual Sports Department
Higher Institute of Sport and Physical
Education of Ksar Saïd,
Manouba University
2010 Manouba, Tunisia.
E-mail: bessem_gym@yahoo.fr
Tel: +216 23066716

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