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Original Article

Comparative study of stag leap performance in rhythmic gymnastics: Motion analysis of two different take-off techniques

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Abstract
Problem statement: Rhythmic gymnastics is known for its graceful, fluid movements requiring strength and dynamism, particularly in jumping. Jumps are a crucial component of rhythmic gymnastics routines, requiring high motor coordination in the upper and lower limbs. **Purpose:** In this case study, we performed a pilot investigation into the differences in performance of the stag leap executed with two take-off techniques using kinematic and dynamic parameters. To gain comprehensive insights, we employed a gold-standard motion analysis system. **Approach:** The sample consists of a 23-year-old competitive gymnast. Data were collected using the BTS Bioengineering integrated multifactorial optoelectronic system, comprising six BTS Smart-DX cameras and seven BTS-6000 force platforms. Additionally, fifteen passive markers, adhering to the Helen–Hayes protocol, were applied to specific anatomical landmarks on the athlete's body. Two additional cameras were used for video support during the acquisitions. **Results:** The results show that executing the stag leap with a two-foot take-off produces higher jump height, amplitude, and ground reaction force compared to the same jump performed with a one-foot take-off. Furthermore, the angle of the vector at maximum force tends to be more vertical in the two-foot take-off compared to the jump executed with a one-foot take-off. **Conclusions:** The results provided a quantitative understanding of aspects previously known only qualitatively. By relating qualitative aspects to quantitative data, the study described specific parameters crucial for defining jump technique with favorable biomechanical characteristics, thereby enhancing performance. This contributes significantly to the development of effective training methodologies based on scientific research.
Keywords: performance analysis, training, gymnast, multifactorial optoelectronic system

Introduction

Rhythmic gymnastics is characterized by elegance, fluidity, harmony and rhythmic movements. During the years, different aspects of rhythmic gymnastics have been studied: the pedagogical and didactic approach (Coppola & Vastola, 2019), health promotion (Mischenko et al., 2023; de Oliveira et al., 2021; Coppola et al., 2015), physical activity and technical execution (Donti et al., 2016), the role of coaches (Marais et al., 2023) and studies of body difficulties (Ors, 2020; Batista et al., 2019; Leandro et al., 2017).

Equally important, however, are the strength and dynamism which are expressed in particular in jumping performance. Jumps are highly dynamic motor tasks (Chiriac et al., 2021) that require good elevation and amplitude, good balance in flight, coordination, strength, speed, elasticity and considerable body control (Marcolin et al., 2019). Hutchinson et al. (1998) and Ashby & Heegaard (2002) believe that jumps are an essential part of rhythmic gymnastics exercises and describe them as movements that require complex motor coordination in the upper and lower limbs. Muscle strength, explosiveness, speed, muscle elasticity and motor coordination, in fact, affect jumping performance (Çimen, 2012). Strength plays a decisive role in this discipline. It, combined with flexibility, is useful for achieving high-level performance (Douda et al., 2002). Muscle elasticity and joint mobility are important components for functional body movement (Aji-Putra et al., 2021). Strength and flexibility, therefore, are the two factors that show skill in rhythmic gymnastics (Battaglia et al., 2014). In particular, explosive strength is considered the main component of strength in this discipline (Laffranchi, 2001). An important parameter used to evaluate the explosive strength of the lower limbs is the vertical impulse. It is directly linked to the executive quality of the motor task (Santos et al, 2016).

In this regard, Kyselovičová et al. (2020) analyzed the explosive strength and kinematic parameters of the stag leap with back bend of the trunk. The results of the study showed that this jump can be considered one of the most challenging, as its execution requires good coordination of different body segments and high concentrations of strength especially in the abdominal and dorsal muscles. Furthermore, being involved many joints, this jump requires great explosiveness and flexibility.

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Also Petry (2008) defines jumps as the most difficult body elements to perform correctly because there is a need to coordinate the movements of the legs, arms, trunk and head and also one of the rhythmic gymnastics apparatus (rope, hoop, ball, clubs and ribbon), when present. The study conducted by Akkari-Ghazouani et al. (2020), in fact, showed differences in the dynamic and kinematic parameters in the stag leap with ring with the introduction of ball handling. In particular, the parameters changed according to the moment the ball was thrown and, consequently, the introduction of the apparatus caused a change in the performance factors.

It is important, therefore, to study and investigate the dynamics and kinematics parameters of jumps, especially with technologies that allow to have a greater objectivity and accuracy of the data such as the integrated multifactorial optoelectronic system, which represents the gold standard for motion analysis. In this regard, the study carried out by Coppola et al. (2023) investigated the effectiveness of this system to analyze the dynamic and kinematic parameters of complex motor tasks such as jumps in rhythmic gymnastics performed with and without apparatus.

The motor task considered in this study is stag leap. This body difficulty (BD) requires that, in flight, the front leg is flexed to the maximum and the back leg is extended horizontally and parallel to the ground, as shown in figure 2. As described in the 2022-2024 Code of Points (CoP), this jump has a value of 0.20 points.
The run-up phase preceding the jump can be carried out with running or with the chassè step. In particular, the study conducted by Coppola et al. (2020) showed that the height of the sacrum is greater using running, while the maximum elevation and the greatest angle of flexion-extension of the hip joint are obtained with the chassè step. Therefore, with the chassè step you have a better execution of the jump.

The take-off phase preceding the jump is important to develop the energy of the jump and increase its height during the flight phase (Aparo et al., 1999). The take-off can be on one or two feet (Polat, 2018). The study conducted by Akkari-Ghazouani et al. (2023) investigated the kinetic and kinematic variables of the stag leap with ring performed with the one-foot take-off and with the glissade step associated with the throw of the ball. In this phase the swing of the arms also occurs, precisely when the athlete flexes the leg (one-foot take-off) or both legs (two-feet take-off) (Lisitskaya, 1995). The movement of the arms is important for the take-off action, allowing to obtain a greater flight time and increase the body stability (Bobo & Sierra, 1998).

Subsequently, during the flight phase, the shape of the jump must be fixed and well defined (Di Cagno et al., 2008). This phase depends on the quality of the take-off and its duration is influenced by the muscular power and jump height (Santos et al, 2016). A well-executed jump, in fact, requires a precise and rapid take-off phase (Purenović et al., 2010). Furthermore, during the execution of the jump is also important to point the feet, in order to extend the lines of the legs (Błażkiewicz et al., 2019). The last phase is the landing which, especially for complex motor tasks such as jumps in rhythmic gymnastics, is complex (Panzer, 1987) and important for preventing injuries particularly to the hip and knee joints (Błażkiewicz et al., 2019). In this phase the kinetic energy of the body is absorbed and balance is maintained (Christoforidou et al., 2017).

Studying the components of the jump, analyzing the dynamic and kinematic parameters, therefore, allows to provide the athlete and the coach with feedback for the improvement of performance (Cicchella, 2009).

Since in the scientific literature there are not many studies that analyze the biomechanics of the stag leap performed with two different take-off techniques, the aim of this case study is to conduct a pilot investigation to analyze the differences in performance, through the kinematic and dynamic parameters, of the stag leap performed with the take-off on one and two feet, in an equipped laboratory of motion analysis, using the integrated multifactorial optoelectronic system (gold standard for motion analysis). Qualitative and quantitative parameters are integrated in the research, allowing a complete view of the motor task analyzed. In particular, are analyzed: the maximum height of the sacrum, the maximum amplitude of the jump, the Ground Reaction Force (GRF) and the angle of the vector in maximum force.

A qualitative-observational analysis of the stag leap performed with the two take-off techniques was carried out, identifying the parameters that define a good execution of the jump (maximum height and amplitude of the jump). At the same time, a quantitative analysis of the data obtained was carried out to describe the dynamic and kinematic parameters of the jump.

Materials and methods

Participants

This is a case study; therefore, the sample consists of a 23-year-old competitive gymnast who took part in the Gold competitions organized by the Italian Gymnastics Federation (FGI) which represents the top level in rhythmic gymnastics. She was chosen for the study because she is an experienced athlete in this discipline and in the execution of the chosen motor task (stag leap performed with the take-off on one and two feet). The athlete is in good health and has not reported injuries in the months preceding the acquisitions.
The athlete signed the informed consent form to participate in the study.

Instruments

The BTS Bioengineering integrated multifactorial optoelectronic system was used in the study, which represents the gold standard for the motion analysis. In particular, were used: six BTS Smart-DX cameras, seven BTS-6000 force platforms, fifteen passive markers and two cameras for video support.

Procedure

The study was conducted at the Laboratory for Innovative Teaching Methodologies and Analysis of Sports Performance of the University of Salerno. The acquisitions were carried out in two days. A pilot investigation was carried out to verify the correct administration of the movement analysis protocol. This investigation was conducted in the same laboratory, with the same technologies and on a sample similar to that of the study. Initially, the system was calibrated through the Axes, Platform and Wand sequences.

Subsequently, the athlete's anthropometric measurements were taken. In particular: body weight, height, leg length (measuring the distance between the anterior superior iliac spine and the medial malleolus), pelvis width (measuring the distance between the anterior superior iliac spines with a pelvimeter), pelvis height (taking the measurement perpendicular to a ruler placed parallel to the table passing through the greater trochanter and the anterior superior iliac spine), the diameter of the knee (measuring the distance between the femoral epicondyles of the knee) and the diameter of the ankle (measuring the distance between the medial and lateral malleoli) (Vastola, 2018).

Before the acquisitions, the gymnast carried out standardized neuromuscular activation with warm-up and joint mobility exercises of the lower limbs and the muscles involved in carrying out the motor task. Following the warm-up phase, the fifteen passive markers were applied on the athlete's body repere points following the Helen-Hayes protocol. The markers were placed on the sacrum, on the anterior-superior iliac spines, on the lateral epicondyles, on the lateral malleoli, on the heels and on the second metatarsal heads. Furthermore, four bars covered with a marker were used, two of which were placed on the thighs in alignment with the greater trochanter of the femur and the markers on the epicondyles and two on the legs aligned with the markers on the epicondyles and those on the lateral malleoli (Kadaba et al., 1990).

Before the jump trials, a static acquisition was carried out in which the athlete was in orthostasis on the force platforms to ensure that the system identified the markers compared to the reference biomechanical model. Finally, the athlete moved to the realization of the dynamic acquisitions of the chosen motor task, i.e. the stag leap performed with the take-off on one and two feet. Seven jump tests were carried out for each variant and, subsequently, the five best trials were selected in terms of performance and quality of data acquisition.

Data collection and analysis

Data processing and analysis were carried out with SMARTtracker and SMARTanalyzer software. SMARTtracker allowed to assign a name to each marker, thus reconstructing the jumping movement based on the reference biomechanical model (Helen-Hayes protocol), as shown in figure 1. This software was also used to identify Ground Reaction Force (GRF) upon feet contact with the force platforms.

The SMARTanalyzer software was used to calculate the values of maximum amplitude of the leap, maximum height of the sacrum during the jump and the angle of the vector in maximum force.

All the data collected were entered into Excel tables to carry out a descriptive statistical analysis. In particular, the mean and standard deviation values were highlighted. Furthermore, the differences expressed in percentage values (%) with respect to the maximum height of the sacrum, the maximum amplitude of the jump, the Ground Reaction Force and the angle of the vector in maximum force relating to the two jump take-off techniques were calculated.

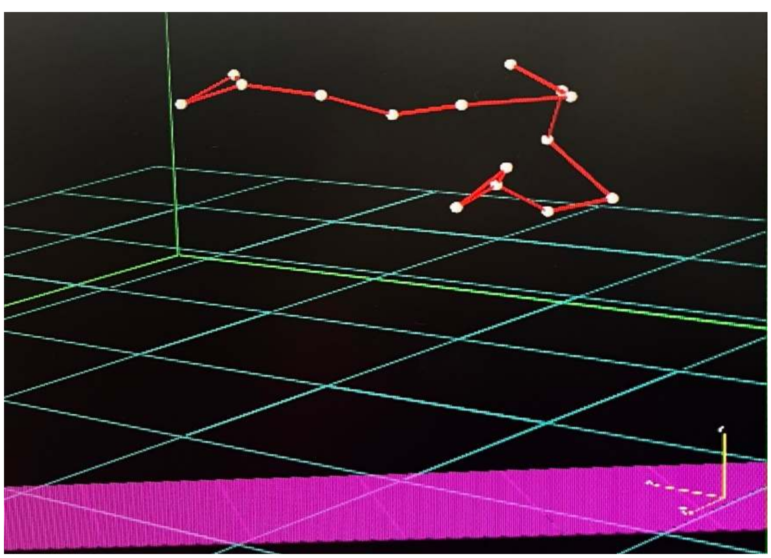

Figure 1: Representation of the stag leap with the SMARTtracker software

Figure 2: Representation of the stag leap

Results

Table 1: Data relating to the maximum height of the sacrum of the stag leap performed with the two take-off techniques

Maximum height of the sacrum	
	Mean values
Take off on one foot	1.294 m ± 0.0095
Take off on two feet	1.308 m ± 0.0115

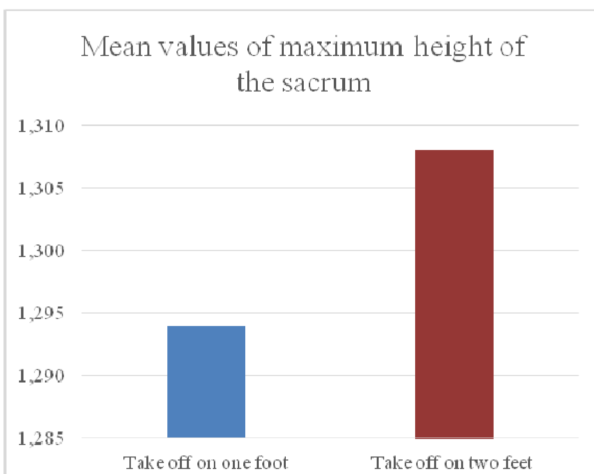

Figure 3: Mean values of the maximum height of the sacrum of the stag leap performed with the take-off on one and two feet

Table 1 and figure 3 show the mean values of maximum height of the sacrum of the stag leap performed with the take-off on one and two feet. In particular, it can be seen that in the one-foot take-off the maximum height of the sacrum is 1.294 m ± 0.0095, while in the two-feet take-off it is 1.308 m ± 0.0115.

Furthermore, the maximum height values of the sacrum with the two-feet take-off are 8% higher than the jump performed with the single-foot take-off.

Table 2: Data relating to the maximum amplitude of the stag leap performed with the two take-off techniques

Maximum amplitude of the leap	
	Mean values
Take off on one foot	137.03° ± 5.761
Take off on two feet	162.92° ± 5.596

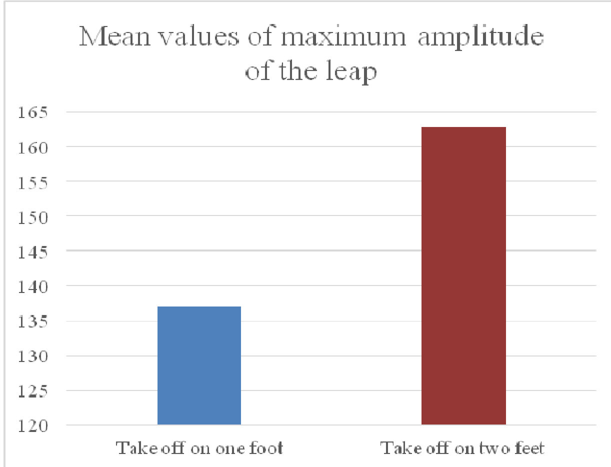

Figure 4: Mean values of the maximum amplitude of the stag leap performed with the take-off on one and two feet

Table 2 and figure 4 show the mean values of maximum amplitude of the stag leap performed with the take-off on one and two feet. In particular, for the one-foot take-off the mean value is 137.03° ± 5.761, while that for the two-feet take-off is 162.92°± 5.596.

The maximum amplitude values of the jump with the take-off on two feet are 19% higher than those of the jump performed on one foot.

Table 3: Data relating to the Ground Reaction Force of the stag leap performed with the two take-off techniques

Ground Reaction Force	
	Mean values
Take off on one foot	1586.118 N ± 69.147
Take off on two feet	2245.172 N ± 131.887

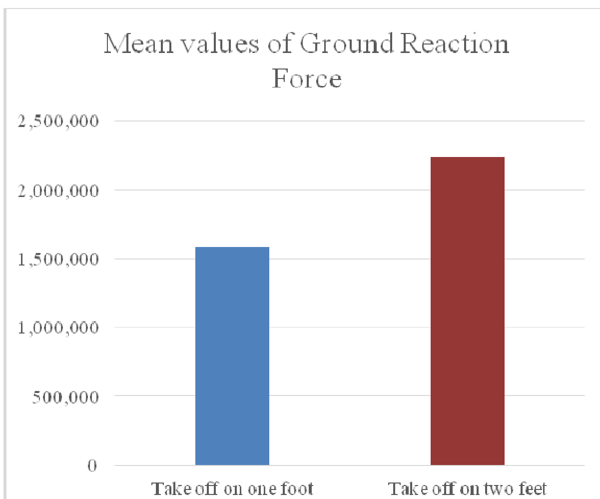

Figure 5: Mean values of the Ground Reaction Force of the stag leap performed with the take-off on one and two feet

Table 3 and figure 5 show the mean values of the Ground Reaction Force (GRF) of the stag leap performed with the take-off on one and two feet. In particular, the GRF in the stag leap with the one-foot take-off is 1586.118 N ± 69.147, while the GRF in the two-feet take-off is 2245.172 N ± 131.887.

Furthermore, the GRF values with the two-feet take-off are 42% higher than the jump performed with the one-foot take-off.

Table 4: Data relating to the angle of the vector in maximum force of the stag leap performed with the two take-off techniques

Angle of the vector in maximum force	
	Mean values
Take off on one foot	113° ± 1.38
Take off on two feet	99.8° ± 2.3

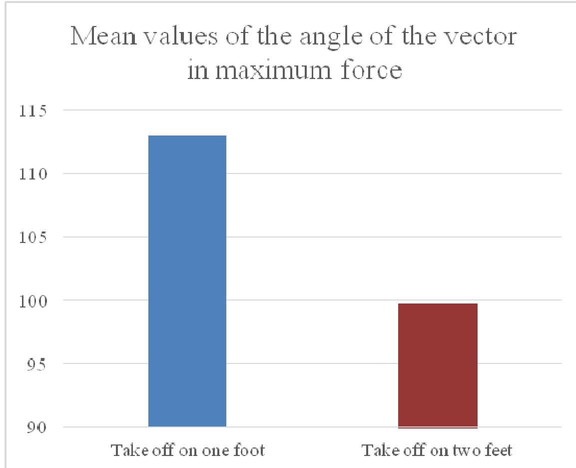

Figure 6: Mean values of the angle of the vector in maximum force of the stag leap performed with the take-off on one and two feet

Table 4 and figure 6 show the mean values of the angle of the vector in maximum force of the stag leap performed with the take-off on one and two feet. In particular, for the one-foot take-off the mean value of the angle of the vector is 113° ± 1.38, while for the two-feet take-off it is 99.8° ± 2.3.

The angle of the vector in maximum force values of the stag leap performed with the two-feet take-off are 12% lower than jump performed with the one-foot take-off.

Discussion

The aim of the study was to investigate the differences in performance between the two stag leap take-off techniques in rhythmic gymnastics, using the integrated multifactorial optoelectronic system, which represents the gold standard for motion analysis. The results of the study made it possible to quantify aspects known only from a qualitative point of view. In particular, as shown in table 1 and figure 3, it was found that the maximum height values of the sacrum are greater in the stag leap performed with the take-off on two feet (1.308 m ± 0.0115 vs 1.294 m ± 0.0095), with a percentage value equal to 8% higher than the jump performed with the take-off on one foot. Consistently, the results of maximum amplitude of the leap (table 2, figure 4) were also greater in the trials with the two-feet take-off (162.92° ± 5.596 vs 137.03° ± 5.761), with a percentage value equal to 19% higher than the jump performed with a take-off on one foot. Furthermore, the Ground Reaction Force values were also, naturally, greater in jumps performed with the take-off on two feet (2245.172 N ± 131.887 vs 1586.118 N ± 69.147), as described in table 3 and figure 5, with a percentage value of 42% higher than the jump performed with one-foot take-off.

The use of the integrated multifactorial optoelectronic system made it possible to perform a qualitative analysis of the jumps, identifying the parameters that indicate good execution of the task. The qualitative analysis was enriched by the synchronization of quantitative data that allowed to describe the intrinsic biomechanical parameters of the jump task (dynamics analysis) and kinematics (photogrammetry system with passive markers, shown in the figures 1 and 2).

The integrated and synchronous comparison of qualitative data with quantitative data showed interesting results that can only be acquired in a motion analysis laboratory equipped with the integrated multifactorial optoelectronic system. It was possible to note that is, with the take-off on one foot, the maximum height of the sacrum does not correspond to the shape (amplitude) of the stag leap described in the 2022-2024 Code of Points, as it occurs in two phases: when the front leg reaches maximum flexion, the back leg is still in the rising phase; while, the back leg reaches maximum elevation when the front leg is descending.

The two-feet take-off allows the simultaneous elevation of both limbs with a higher Ground Reaction Force value (2245.172 N ± 131.887) compared to the one-foot take-off (1586.118 N ± 69.147). Furthermore, the angle of the vector in maximum force in the two-feet take-off is also more vertical (99.8° ± 2.3) compared to the take-off on one foot (113° ± 1.38), as shown in table 4 and figure 6. This data represents an additional characteristic of a quantitative nature that affects the determination of the elevation values reached in the jumps.

Conclusion

This study has allowed to relate the qualitative aspects to the quantitative ones, describing specific parameters useful for defining the jumping technique that has favorable biomechanical characteristics for better performance. As can be seen from the results, performing the stag leap with the take-off on two feet is more effective in biomechanical terms (height and amplitude of the jump and ground reaction force) than the take-off on one foot. Athletes are therefore advised to use in their routines the stag leap performed on two feet.

It is desirable to conduct a survey on a larger sample of gymnasts of different levels and ages in order to describe and analyze in a more exhaustive way the quali-quantitative parameters of the two jump take-off techniques.
In conclusion, this study leads to reflect on the potential in the use of gold standard technologies, used for the instrumental analysis of movement, for the analysis of sports performance of complex motor tasks such as the stag leap in rhythmic gymnastics, contribute to the development of effective training methodologies based on scientific research.

Disclosure statement
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Ethical approval
This trial is conducted in accordance with ethical principles of the Declaration of Helsinki. Declaration of Helsinki Ethical Principles for Medical Research involving human subjects (WMA, 2013).
Consent to participate
The gymnast signed an informed consent form, authorizing her participation in the study.
Data availability statement
Data available on request.
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