ORIGINAL ARTICLE

Evaluating variability in rhythmic gymnastics: Analysis of split leap using the gold standard motion analysis system

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ABSTRACT

Recent research suggests that variability enhances motor control, learning, and adaptation by improving the system's response to environmental demands. It also develops the cognitive and executive functions of athletes. The purpose of the study is to evaluate the variability of the split leap in rhythmic gymnastics, performed with and without ribbon handling, analysing in which of the two techniques there is greater variability. The sample consists of six competitive gymnasts with an average age of 15.1 years (±0.94). The acquisitions were carried out with the BTS Bioengineering integrated multifactorial optoelectronic system, using fifteen passive markers, six BTS Smart-DX cameras, two cameras for video support and seven BTS-6000 force platforms. The results show that the coefficient of variation (CV%) in trials performed with ribbon is higher than those without the apparatus. Cohen's Effect Size revealed a small effect size between trials with ribbon and those without. Despite being minimal, this difference emphasizes the presence of variability in jumps executed with ribbon in comparison to free body trials. In conclusion, this study explored both intrinsic (CV%) and extrinsic (task complexity, technical experience) factors of jump performance, highlighting the utility of gold standard motion analysis systems for researching executive variability in rhythmic gymnastics jumps.
Keywords: Performance analysis, Motor control, Training, Gymnasts, Skill acquisition, Multifactorial optoelectronic system.

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INTRODUCTION

The human body produces variable patterns and movements (Gray, 2021). Movement variability has always been defined as noise to be reduced or eliminated because it is associated with technical errors during the execution of a motor task (Seifert et al., 2013; Stergiou et al., 2013; Kudo & Ohtsuki, 2008). Many coaches, in fact, think that variability is a noise that intervenes in athletes' learning of a motor skill, producing different rhythms and modifying performances (Liu et al., 2006). Recently, however, thanks to the studies conducted by James, Newell et al., variability has assumed positive acceptance as it could provide the movement system with good adaptability and flexibility (Newell & James, 2008; Riley & Turvey, 2002; Newell & Slifkin, 1998) to cope with the demands of the surrounding environment. Therefore, variability represents a functional aspect for improving motor control and, consequently, learning and adaptation (Barbado et al., 2012; Manor et al., 2010). Adding perturbations to the system, in fact, as Davids et al. (2004) suggest, is useful for making signals deriving from the environment more visible. Furthermore, variability plays an important role in performance as it provides the necessary fluctuations that allow individuals to refine and adapt acquired movement patterns (Davids et al., 2003; Newell, 1985).

Variability in sports practice also affects the development of the athlete's cognitive and executive functions. Innovation, diversity and engagement, belonging to the construct of variability, are essential to make learning experiences meaningful, as described in the ecological approach to learning motor skills (Pesce et al., 2016).

The quantity and complexity of the variability depend on the health status of the performer, the degree of learning and the conditions in which the acquisitions are made (Winter, 1983).

Furthermore, the skill to be performed and the environment in which it is performed are also considered factors that influence performance variability (Malcata & Hopkins, 2014).

Even in high-level athletes there are variable movements, although, apparently, they seem to repeat the same actions to obtain the same result (Bernstein, 1967). This happens because, during the execution of a movement, the internal and external conditions of the body are never identical to the previous ones. In this regard, we talk about 'variability conditioned by the context' (Fitch, 2014), according to which body movements are conditioned by changing internal and external factors. For this reason, you will never have exactly same movement results.

In the literature, variability is also related to the complexity of the tasks to be performed and to motor learning. In this regard, according to Gentile's Multidimensional Classification System (2000), the movement of the body in space, associated with the manipulation of objects, is considered a complex and variable condition. Therefore, one of the principles of motor learning that interacts with the variability of practice is the complexity of the activity to be performed (Kaipa, 2016). Inserting a task constraint, in fact, influences both the variability and complexity of the motor task (Nohelova et al., 2021). The complexity of the task to be performed also significantly affects the variance of the individual's learning rates (Nembhard & Osothsilp, 2002).

Below are presented several studies from the scientific literature that investigate the variability in relation to the complexity of the motor task and the athletes' level of mastery of the task. In particular, reference is made to situational sports such as rugby, football and Australian football.

In rugby, Pearce et al. (2020) conducted a study to examine the relationship between the evasive skills to be used in the match and the degree of motor development of athletes. This study demonstrated that the type of evasive skill and its variability depend on the athletes' level of motor development.

McLaren et al. (2016) and Kempton et al. (2014) examined the variability in low, high, and very high speed running performance of rugby athletes. By calculating the coefficient of variation (CV%), greater variability emerged in high intensity activity. Furthermore, the data shows that the position of the players on the pitch influences the variability in their performances. Therefore, part of the inter- and intra-subject variability can be explained by the characteristics of the players and the tactical roles they play.

These results are also found in football and Australian football. In fact, in the study by Trewin et al. (2018), which examined the degree of variation in the run of 45 female players, and in the study of Kempton et al. (2015) found that CV% was lower in low-intensity activities and higher in sprints and during high-intensity activities. Therefore, the variability of movements increases as the speed of actions is increased.

Furthermore, as in the McLaren et al. (2016) study carried out with rugby players, these researches also show that the variation in speed was due to the role played by the athletes in the match.

Even the study conducted by Liu et al. (2016) explored the match-to-match variation of footballers by calculating CV% at different points in matches. The data revealed a difference in technical performance between the players of the stronger and less strong teams and that the variation in performance is influenced by the game context and the opponents. In line with the studies in the literature, these results underline how the variability in performance depends on the level of mastery of the movement by the athlete.

Other studies on variability have been carried out in artistic gymnastics. In particular, the research by Busquets et al. (2016) has highlighted how the inter-trial variability in bar swings, observed in young and novice gymnasts, was higher than the variability recorded in the same tests carried out by older and more experienced athletes. Therefore, also in this study the relationship between variability, gesture complexity and motor learning are underlined.

Bradshaw et al. (2010) evaluated the validity and reliability of inter-daily training of vaulting exercises using infrared timing systems and a contact mat. Through CV% the variability was measured during the run-up and at the time of contact with the board. For some technical elements performed, the contact times with the carpets showed high variability. This could be due to the touch of the board at different points before the flight, the return of energy generated by the take-off on the board and the flight path of the athletes. Variability, therefore, has a fundamental role in performance because it allows the expert gymnast to perform multiple attempts of the same skill but with different performance patterns especially in terms of muscle coordination, joint coupling and movement kinematics (Latash et al., 2002).

The present study examines the split leap in rhythmic gymnastics. This sport is characterized by elegance, fluidity, harmony, strength and dynamism, which are expressed in particular in jumps performance (Coppola et al., 2024).

Split leap is body difficulty (BD) that, as described in the 2022-2024 Code of Points (CoP), has a value of 0.30 points and involves a split in flight bringing the dominant leg forward and the non-dominant leg backwards, reaching an amplitude of at least 180°. This jump requires great qualities of speed, explosive strength, body control and coordination (Aparo et al., 1999).

The jump involves three fundamental phases: the run-up, the flight phase and the landing. The run-up can be carried out with a run or with the chassè step (Coppola et al., 2020). During the flight phase, the shape of the BD must be fixed and well defined and the elevation must allow the desired figure to be achieved (Di

Cagno et al., 2008). The landing phase is very important because, as underlined in the study conducted by Błażkiewicz et al. (2019), the hip and knee joints are the most vulnerable to injuries. Variability, in fact, is also useful in the prevention of injuries (Bartlett et al., 2007) because it allows to distribute on several joints the high and protracted forces over time (Nordin & Dufek, 2019). Reduced variability can lead to increased mechanical stress on the anatomical structures involved in the motor task, representing a predisposing factor to injuries (Barrett et al., 2008). Moreover, in the absence of adequate movement variability, adaptation is not promoted and, consequently, the continuous application of the load can lead to injury to the joints and tissues involved (James, 2004).

In scientific literature, variability research uses technologies such as GPS, triaxial accelerometers, gyroscopes, magnetometers, infrared timing systems and contact mats. However, there are no studies that deal with the variability of technical gestures in rhythmic gymnastics with the use of the integrated multifactorial optoelectronic system, considered the gold standard for motion analysis. In this regard, the study by Coppola et al. (2023) investigated the effectiveness of the integrated multifactorial optoelectronic system to analyse the dynamic and kinematic parameters of complex motor tasks such as the split leap performed with and without the ribbon.

Other studies on rhythmic gymnastics concern the kinematic parameters of the run-up phase of the jump performed with the simple run and the chassè step (Coppola et al., 2020); the take-off with one and two-feet (Polat, 2018) and with the glissade-step technique (Akkari-Ghazouani et al., 2022); the relationship between body composition, flexibility and explosive strength of the lower limbs in jumping performance (Aji-Putra et al. 2021) and the dynamic and kinematic parameters of jumps performed with and without apparatus (Mkaouer et al., 2012).

The aim of this study is to evaluate the executive variability (CV%) in the horizontal split of the split leap performed with and without ribbon, analysing in which of the two techniques there is greater variability. It is assumed that the trials performed with the ribbon have a greater variability due to the inclusion of the handling of the tool during the jump which makes the motor task more complex.

MATERIAL AND METHODS

Participants

Six top level gymnasts aged between 13 and 16 took part in this study. The average age is 15.1 years (±0.94). The gymnasts were randomly selected from a group of top-level (N = 30) gymnasts who competed for at least two years.

The athletes compete in Gold and Silver competitions organized by the Italian Gymnastics Federation (FGI). Five out of six female athletes train three hours a day for five days a week, while one gymnast trains three times a week for two hours. Three gymnasts have more technical experience in handling the ribbon.

The gymnasts' parents signed an informed consent form, authorizing their participation in the study.

Instruments

The BTS Bioengineering integrated multifactorial optoelectronic system was used, which represents the gold standard for the motion analysis, consisting of six BTS Smart-DX cameras, three of which are placed anteriorly and three posteriorly to the acquisition volume; two cameras for video support; seven BTS-6000 force platforms and fifteen passive markers.

Survey

A survey was given to the athletes regarding the years of sporting experience, the hours and days of weekly training, the level of experience in using the ribbon in training and competition and based on previous experience, their considerations on the execution of the split leap with and without a ribbon and with the chosen handling (serpentines above and behind the head).

Procedures

The study was conducted at the Laboratory for innovative teaching methodologies and analysis of sports performance of the University of Salerno. The acquisitions were conducted within a week. A pilot investigation was carried out to verify the correct administration of the movement analysis protocol. This investigation was conducted in the same laboratory and 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 following anthropometric measurements of the athletes were taken: the body weight; the height; the length of the legs, measuring the distance between the anterior superior iliac spine and the medial malleolus; the width of the pelvis with a pelvimeter, measuring the distance between the anterior superior iliac spines; the height of the pelvis, 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 knees, measuring the distance between the femoral condyles of the knee and the diameter of the ankles, measuring the distance between the medial and lateral malleoli (Vastola, 2018).

All the gymnasts carried out standardized neuromuscular activation with warm-up and joint mobility exercises of the lower limbs and the muscles involved in the realization of the motor task.

Then, fifteen passive markers were applied on the landmarks of the athletes' body following the Helen Hayes protocol. In particular, the markers were positioned 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. In addition, four bars covered with a marker were used, two of which were positioned 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).

The split leap, being a very fast motor task, resulted in high muscle vibrations. Consequently, it was necessary to pay attention to the positioning of the markers on the anatomical landmarks and, in some cases, it was useful to further block the markers by applying adhesive tape around them.

To identify the position of the markers with respect to the biomechanical model, static acquisitions were carried out in which the athletes were in orthostasis on the force platforms. The next step was the dynamic acquisition of the motor task. The athletes performed five trials of the free body split leap and then five trials of the same jump with the ribbon. The handling of the tool consisted of coils above and behind the head.

Analysis

The data were processed and analysed using SMARTtracker and SMARTanalyser software. Specifically, SMARTtracker was employed to track the jump trials, assigning names to each marker based on the reference biomechanical model (Helen Hayes protocol) and to identify the ground reaction force (GRF).

Instead, with the SMARTanalyser software, the split amplitude event (°) was identified at the instant in which the two limbs were parallel to the ground.

A qualitative analysis was first carried out, viewing videos of the jumps and selecting the best performances based on the correct execution of the leap's technical movement.

Subsequently, with quantitative analysis, the coefficient of variation (CV%) for the maximum horizontal split was calculated in both free body and ribbon jumps. A statistical analysis of Cohen's Effect Size and a hypothesis test were carried out with MATLAB software. The normality of the distribution of the data of free body and ribbon trials was verified using the Shapiro-Wilk test. Subsequently, the t-test for independent samples was useful to verify whether the difference in the mean values of the tests with and without ribbon was statistically significant.

RESULTS

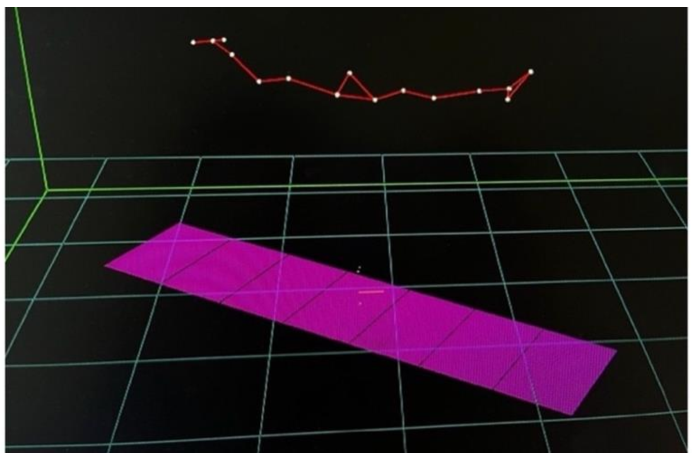

Figure 1. Representation of split leap with the SMARTtracker software.

Table 1. CV% of the horizontal split with and without ribbon.

CV of the horizontal split (%) without ribbon	0.521 ± 0.26
CV of the horizontal split (%) with ribbon	0.591 ± 0.25

Table 1 shows the coefficients of variation (CV%) of the horizontal split of the split leap (shown in Figure 1) performed with and without ribbon. In particular, the CV of the horizontal split without ribbon is 0.521 ± 0.26, while the CV of the split with ribbon is 0.591 ± 0.25.

Table 2. *p*-Value of the Shapiro-Wilk test.

p-value of Shapiro-Wilk test without ribbon	.842
p-value of Shapiro-Wilk test with ribbon	.167

Table 2 shows the *p*-values of the Shapiro-Wilk test. Regarding the trials carried out without ribbon, the *p*-value is .842, while the *p*-value of the trials with ribbon is .167.

The Cohen's Effect Size result is 0.3. Therefore, according to McGuigan's (2017) guidelines, the effect size is small.

The *p*-value of the t-test for independent samples is .674.

Table 3. CV% of horizontal split with ribbon for each gymnast.

	CV% of horizontal split with ribbon
Expert gymnasts in handling ribbon	
Gymnast 1	0.2
Gymnast 2	0.378
Gymnast 3	0.395
Less expert gymnasts in handling ribbon	
Gymnast 4	0.79
Gymnast 5	0.81
Gymnast 6	0.9

Table 3 shows, for expert and less expert gymnasts in handling the ribbon, the coefficients of variation (CV%) of the horizontal split of the split leap performed with the ribbon.

DISCUSSION

From the results obtained using the Shapiro-Wilk test, which verifies the normality of the data distribution, it emerges that both *p*-values (.842 for the trials without ribbon and .167 for those with ribbon) are greater than .05, therefore, the data were normally distributed. Subsequently, the t-test for independent samples was carried out to compare the jump trials data with and without apparatus. The result shows a *p*-value (.674) greater than .05, indicating no statistically significant evidence of a meaningful difference in the mean values of the jumps performed free body and with ribbon. This is probably due to the small sample size of the study which does not allow to draw conclusions representative of the entire population of gymnasts.

Significant findings relate to the coefficients of variation (CV%) and the value of Cohen's Effect Size. As regards the CV, it is higher in the jumping trials performed with ribbon (0.591 ± 0.25) compared to the free body ones (0.521 ± 0.26). Therefore, these results show how the introduction of a task constraint (handling the ribbon during the execution of the jump) influences the execution of the motor task, making it more complex and, consequently, also more variable (Nohelova et al., 2021; Kaipa, 2016; Gentile, 2000).

Furthermore, Cohen's Effect Size also shows a difference, although minimal, between the jump trials performed free body and with ribbon. In fact, although the size of the effect relating to the use of the apparatus (0.3) is small (McGuigan 2017), it indicates the presence of a difference between the two values. This reflects the starting hypothesis, i.e. that the jumps performed with the ribbon have greater variability due to the complexity of the motor task (split leap with the addition of handling the apparatus). These results are in line with the studies in scientific literature regarding the variability and complexity of the task (Nohelova et al., 2021; Kaipa, 2016; Nembhard & Osothsilp, 2002; Gentile, 2000).

A further finding of interest emerged from the comparison of the CV% of the horizontal split between the more and less experienced gymnasts using a ribbon. As shown in Table 3, a lower CV% was detected in the more experienced gymnasts compared to the less experienced counterparts (0.2, 0.378, 0.395 vs 0.79, 0.81, 0.9).

These results are fully consistent with other studies conducted in scientific literature on motor tasks of other sports activities that have investigated performance levels in relation to the variability, complexity of the task and the experience of the athletes (Pearce et al., 2020; Trewin et al., 2018; Busquets et al., 2016; Liu et al., 2016; McLaren et al., 2016; Kempton et al., 2015; Kempton et al., 2014; Bradshaw et al., 2010).

CONCLUSIONS

Given the absence of specific studies on variability in rhythmic gymnastics, particularly concerning the split leap with and without apparatus, a direct comparison of data was not possible.

The integrated multifactorial optoelectronic system, considered the gold standard for motion analysis, has proved to be an effective technology for evaluating aspects relating to the variability of a motor task with high complexity and executive speed such as the split leap, with the addition of handling five meters ribbon. This system allowed to obtain more accurate and detailed quantitative results compared to traditional systems, such as GPS, triaxial accelerometers, gyroscopes and magnetometers, used in other research conducted in this field of study. The use of this technology enabled a comprehensive analysis, combining quantitative (integrated multifactorial optoelectronic system) and qualitative (video analysis) methods, obtaining consistent results on a qualitative-quantitative level.

In conclusion, although the results obtained are not representative of the population of gymnasts, due to the limited sample size, this study allowed to investigate simultaneously intrinsic (CV%) and extrinsic aspects (task complexity and technical experience) of sports performance of a jump in rhythmic gymnastics.

Finally, this study opens a reflection on the potential in the use of gold standard system for the motion analysis for research on executive variability in the jumping tasks in rhythmic gymnastics.

AUTHOR CONTRIBUTIONS

The article is the result of a collaborative work by all the authors. SC, CC and DA contributed to the preparation and research design, data collection, data analysis, result, interpretation, manuscript writing, supervision of the study, and review of the final version. RV is the scientific coordinator of the study. All authors have read and agreed to the final version of the manuscript and consent to its publication in JHSE.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ETHICAL APPROVAL

These trials are 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 gymnasts' parents signed an informed consent form, authorizing their participation in the study.

DATA AVAILABILITY STATEMENT

Data available on request.

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