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ORIGINAL

PERFORMANCE VARIABLES AND TECHNICAL PENALTIES OF THE SPLIT LEAP

VARIABLES DE RENDIMIENTO Y PENALIZACIONES TÉCNICAS DEL SALTO ZANCADA

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ABSTRACT

The aim of this study was to analyze the relationship between the following aspects: the technical penalties obtained in the execution of an isolated gymnastics element, the competitive level of the gymnasts, their anthropometric characteristics, and the most important temporal and angular variables analyzed in this skill. Twenty nine gymnasts (aged 17.1 ± 3.1 years) from different competition levels were selected. Three coaches evaluated the execution through an adaptation of the Code of Points. Significant direct and indirect associations were observed ($p < 0.05$): low adiposity index ($\rho = 0.643$), take-off total time ($\rho = 0.619$), flight total time ($\rho = - 0.596$),

maximum range of motion of the hips ($\rho = -0.902$), and maximum extension of ankles ($\rho = -0.738$). The assessment of penalties as well as the use of competitive level and Split Leap as specific tests, have demonstrated to be useful tools for evaluating performance.

KEY WORDS: rhythmic gymnastics, photogrammetry, performance

RESUMEN

Se analizó la relación entre las penalizaciones técnicas obtenidas en la ejecución de un elemento gimnástico aislado con el nivel competitivo de las gimnastas, sus características antropométricas y las variables temporales y angulares más importantes analizadas en dicha habilidad. Fueron seleccionadas 29 gimnastas ($17,1 \pm 3,1$ años) procedentes de distintos niveles competitivos. Tres entrenadores evaluaron la ejecución mediante una adaptación del Código de Puntuación. Se observaron asociaciones significativas directas e indirectas ($p < 0,05$): bajo índice de adiposidad ($\rho = 0,643$), tiempo total de batida ($\rho = 0,619$), tiempo total de vuelo ($\rho = -0,596$), máxima amplitud articular de caderas ($\rho = -0,902$) y máxima extensión de los tobillos ($\rho = -0,738$). La valoración de las penalizaciones así como el uso del nivel competitivo y del Salto Zancada como test específico han resultado ser herramientas útiles para la valoración del rendimiento.

PALABRAS CLAVE: gimnasia rítmica, fotogrametría, rendimiento

INTRODUCTION

Rhythmic gymnastics (RG) performance is assessed through the scores or punctuations that judges grant during the performance of the exercise in a competition following the rules established by the International Gymnastics Federation (FIG) in the Code of Points (CoP). It is important to remark that different adaptations of the CoP exist in most countries in order to include all competition levels in which the practice of rhythmic gymnastics is developed. Judges do not evaluate a beginner gymnast and an elite one the same way. They use different criteria when evaluating gymnasts of different competition levels.

The CoP assesses two general aspects of the RG exercise composition: the technical execution (E) and the exercise difficulty value (D). However, it is designed to evaluate complete exercises and not isolated elements. To analyze and assess isolated gymnastic elements, numerous authors have developed biomechanical studies to evaluate the technical execution in gymnastic skills for the purpose of detecting and correcting technical mistakes in order to improve the sports performance (Cicchella, 2009; Rodríguez, Villacieros, & Ferro, 2013; Potop & Timnea, 2012; Se-Mi, Ji-Seon, & Tae-Sam, 2011; Tae-Sam, 2011; Byung-Hoon, Kae-san & Hee-Kyo, 2002). Most of them use some sport

biomechanical techniques like Photogrammetry (Aragón et al., 2010; Grande, Bautista & Hontoria, 2008; Cicchella, 2009; Mkaouer, Amara, & Tabka, 2012; Rodríguez et al., 2013) and high speed video-analysis (Rodríguez et al., 2013; Mkaouer et al., 2014) in order to analyze movement patterns and quantify some kinematic variables (times, angles, speed, etc.).

In addition to assessing the technical execution, other types of variables (anthropometric, conditionals...) that have been measured in scientific literature happen to be decisive for gymnasts' performance. Many authors state the importance of a low subcutaneous fat for the best execution of gymnastic skills (Claessens et al., 1991; Claessens, Lefevre, Beunen, & Malina 1999; Douda, Toubekis, Avloniti, & Tokmakidis, 2008; Romero, Palomino, & González, 2011; Miletic, Katic, & Males, 2004; Miletic & Kostic, 2006; Di Cagno et al., 2008, 2009; Hume, Hopkins, Robinson, Robinson, & Hollings, 1993) as well as the flexibility, explosive strength, and power for the best execution of jumping abilities (Douda et al., 2008; Romero et al., 2011; Miletic et al., 2004; Miletic & Kostic, 2006; Hume et al., 1993). Explosive strength and power are expressed both in general jump test execution (CMJ, SJ, or Hopping test) and in specific RG jumps, establishing a relationship between the two types of jump tests (Di Cagno et al., 2008, 2009; Romero et al., 2011). Flexibility is expressed only in specific rhythmic gymnastics jump tests due to the high requirements of range of motion in the execution of this kind of ability (Di Cagno et al., 2008, 2009; Romero et al., 2011).

Of all specific RG jumps, Split Leap (SL) is the most widely used in scientific bibliography (Di Cagno et al., 2008, 2009; Miletic et al., 2004; Miletic & Kostic, 2006; Grande et al., 2008; Dyhre-Poulsen, 1987; Cicchella, 2009; Mkaouer et al., 2012; Rodríguez et al., 2013) due to the following main reasons: it is one of the most characteristic jumps of RG, it is a simple element that provides a lot of useful information for the coaches (Cicchella, 2009; Grande et al., 2008; Rodríguez et al., 2013), and it is also taught from the initiation into this sport and is still used at all competition levels.

Qualitative assessment of judges is the main way to assess rhythmic gymnastics performance in competition. Punctuation system is geared to assess an entire exercise instead of isolated elements (FIG, 2013). Considering the above and given the evidence of the influence of certain types of variables in the execution of isolated gymnastic skills, we could establish the hypothesis that qualitative assessment of SL could be influenced by the existence of possible correlation between anthropometric and kinematic variables. This could provide sufficient information to indicate or estimate the gymnast's competitive level. For that reason, the aims of this study are the following: 1) to propose a simple way of assessing the technical execution in an isolated element (SL) through an adaptation of the CoP, and 2) to analyze with that the possible relationships between the observed technical penalties, the anthropometric characteristics and the competitive level of the gymnast, as well as the most important kinematic variables analyzed in SL.

MATERIAL AND METHODS

Participants

A total of 29 female RG athletes (age = 17.1 ± 3.1 years, sport experience = 9.3 ± 3.5 years) were selected for this study through a selection process carried out following experts' advice (RG coaches). The selection criteria were the following: first, gymnasts had to master the ability object of this analysis which had to be an already learned skill, not a new element to learn; secondly, to ensure an adequate learning level of that skill and consistency and safety in its execution, gymnasts had to have at least five years of experience in RG, time considered sufficient by some authors for learning and automating basic body difficulties (Zisi, Giannitsopoulou, Vassiliadou, Pollatou, & Kiomourtzoglou, 2009; Miletic et al., 2004, Douda et al., 2008); thirdly, the sample had to include gymnasts from different competitive levels (provincial: $n = 10$, regional: $n = 5$, national: $n = 12$, and international level: $n = 2$) (Douda et al., 2008; Romero et al., 2011). All gymnasts voluntarily agreed to participate in the study through a written informed consent signed by them or by their legal guardians. This consent complied with the ethical standards for human research, according to the principles of the Declaration of Helsinki (World Medical Association, WMA, 2008).

Procedures

The development of this study was conducted in three stages.

1.1 Measurement and record of anthropometric variables

Anthropometric data were collected from each gymnast using standardized protocols (Marfell-Jones, Olds, Stewart, & Carter, 2006; Esparza, 1993). Anthropometric variables included in this study were: weight, height, body mass index (BMI), four skinfolds (triceps, subscapular, suprailiac, abdominal) and sum of the four skinfolds. A wall stadiometer was used for height measurement. Weight was measured on a digital scale with an accuracy of 0.1 kg (Laica SpA, Vicenza, Italy). A Slim Guide caliper (Slim Guide®, Creative Health Products, Michigan, USA) was used to measure skinfold thickness to the nearest 0.5 mm on the right side of the body with the participants in standing position and using a dermatographic pen. All skinfold measurements were performed in triplicate by the same observer, waiting four seconds before each one of them and a pause period between measurements of 1-2 minutes.

1.2 Election of the gymnastic skill for studying

An element that represents one of the RG characteristic abilities was selected. Therefore, it is part of the motor structure of this sport: a jump. Specifically, SL

was chosen. According to the CoP, this is a jump in which the figure of split is shown (FIG, 2013). The reason for choosing this body difficulty is based on the following criteria: first, it is a basic and simple RG ability that every gymnast must master because it is taught and learned since sport initiation; secondly, there exists a progression towards more difficult leaps with greater technical value (FIG, 2013).

1.3 Measurement and record of kinematic variables

The methodology proposed by Rodríguez et al. (2013) for kinematic analysis of technique has been followed in this study. First, gymnasts were filmed performing the SL at a frequency of 240 frames per second using a high speed video camera (Casio Exilim EX-ZR200, Tokyo, Japan). Then, the filmed videos were analyzed through the software Kinovea 0.8.15. (Kinovea.org, France). Two kinds of kinematic variables were quantified to analyze technical execution in SL: Temporal variables (total time of the movement phases: take-off, flight, maximum articular amplitude, landing, and overall execution of the jump) and Angular variables (maximum articular amplitude angles of lower limbs joints during flight phase: Forward ankle extension, Backward ankle extension, Forward hip flexion, Backward hip extension, and Maximum articular amplitude between the two hips).

1.4 Record of criterion variables

Two kinds of variables related to RG performance were used in this study: Competitive level and Penalty score in the execution of SL.

On the one hand, according to the knowledge of experts (RG coaches) and the review of previous studies (Zisi et al., 2009), a categorization of competitive level has been established to represent gymnasts' sport performance level. This categorization is defined by six competition levels: Level 1: Basic Provincial Competition (sports initiation); Level 2: Specialized Provincial Competition (sports improvement); Level 3: National-Regional Competition (results on ranking: medium-low); Level 4: National-Regional Competition (results on ranking: medium-high); Level 5: National-Regional Competition (national medalists); and Level 6: International Competition or members of the National Team. These six levels have been established depending on the type of competition in which gymnasts participate and according to the classification results in official competitions (finish among the top positions and/or be medalists, down the middle or among the last positions).

Moreover, on the other hand, an adaptation of the CoP has been made to easily assess performance in the execution of a RG isolated element (body difficulty) (Miletic et al., 2004; Miletic & Kostic, 2006; Delas, Miletic, & Miletic, 2008). In CoP's punctuation system, Execution judges deduct the observed penalties on an initial note of ten points (FIG, 2013). In this work, technical mistakes observed in SL have been summed, obtaining thus a penalty score. This

penalty score is based on a rating scale from 0 to 5 and it has been constituted in relation to the following qualitative aspects: amplitude, shape and fixation of the difficulty (extension of ankles and knees, fixation of the position, and minimum articular amplitude required) (FIG, 2013). The scale is defined as follows: 0 = no failures (perfect execution of the difficulty, free of technical mistakes); 1 = 1 failure (example: lack of amplitude); 2 = 2 failures (example: lack of amplitude and fixation); 3 = 3 failures (example: lack of amplitude, fixation and no knee extension); 4 = 4 failures (example: lack of amplitude, fixation, no ankle extension...); 5 = 5 failures (very poorly executed difficulty); > 5 failures = The difficulty is not considered as learned. Through this scale it is intended to categorize the technical quality execution of each gymnast as a simple way to assess their performance. For that, three coaches (with the RG national coach title and a high and demonstrable experience in this sport) voluntarily acceded to evaluate the technical execution of SL by watching the videos filmed previously of each gymnast. These coaches were able to distinguish and evaluate technical mistakes in RG body difficulties.

Statistical analysis

Statistical analyses were performed using SPSS software version 22.0 (IBM Corp., Armonk, NY, USA). A Normal distribution was tested with the Shapiro-Wilk-Test. An analysis of the reliability has been made of those variables that were evaluated on more than one occasion. For the measurement of skinfolds, it was made an analysis of the relative reliability through the intra-class correlation coefficient (ICC), and of the absolute reliability through the coefficient of variation (CV). ICC was calculated taking into account the difference in measures and with a confidence interval of 95%, through a one factor analysis of variance (ANOVA) for repeated measures. For the reliability analysis between the scores given in Split Leap, the Kendall's W coefficient of concordance between the three observers was calculated. For each kind of variables, descriptive analyses were calculated. Finally, Spearman correlation coefficient (ρ) was used to analyze the associations between variables. The level of significance was set at 0.05 for all statistical analysis. According to Hopkins (2006) the magnitude of the correlation coefficient was considered to be trivial (0-0.1), small (0.1-0.3), moderate (0.3-0.5), large (0.5-0.7), very large (0.7-0.9) and nearly perfect (0.9-1).

RESULTS

Regarding reliability analysis results of repeated measures (Table 1), observed ICC values in the four skinfolds are higher than 0.9. These data suggest that skinfolds measurements are reliable and have a high internal validity. Regarding the absolute reliability of the four skinfolds measurements, CV results are lower than the 5% maximum advised by GREC (Esparza, 1993).

Table 1. ICC and CV of skinfold measurements.

Skinfold (n = 29)	CV (%)	ICC	CI (95%)	
			Lower limit	Upper limit
Triceps	1.94	0.998	0.996	0.999
Subscapular	2.22	0.997	0.995	0.999
Abdominal	2.67	0.996	0.993	0.998
Supra-iliac	2.28	0.998	0.996	0.999

ICC, intraclass correlation coefficient; CV, coefficient of variation; CI, confidence interval.

As to the results of concordance among the penalty scores provided by the three observers (Table 2), a high Kendall's W coefficient (close to 1) is observed together with a high level of significance ($p < 0.01$). Therefore the concordance among the three observers is significant and shows high reliability (Siegel and Castellan, 1995).

Table 2. Kendall's W coefficient of concordance between the three observers.

Qualitative assessment of the technical execution (scale 0-5)	Kendall's W	Pearson's Chi-squared test
Penalty score in SL (n = 29)	0.798**	67.054

** $p < 0.01$

Significant correlations ($p < 0.01$) have been obtained between the anthropometric and kinematic variables analyzed and the penalty score in SL, as well as the gymnasts' competitive level (Table 3). All anthropometric variables were largely associated with penalty score in SL, except for height. Triceps, abdominal and supra-iliac skinfolds, the body composition measures of BMI and the sum of the four skinfolds were moderately and indirectly associated with competition level ($p < 0.05$). As to kinematic variables, large and very large associations ($\rho > 0.7$) were observed between penalty score, competition level and all angular variables. The only variable which has proved to have a greater association with criterion variables is the angle of maximum articular amplitude between the two hips (Figure 1). Take-off total time and flight total time were significantly correlated ($p < 0.01$) with penalty score in SL and with the gymnast's competitive level. Maximum articular amplitude total time has shown no significant correlation with any of the criterion variables (Table 3).

Table 3. Significant correlations between the anthropometric and kinematic characteristics and the criterion variables.

Variables analyzed (n = 29)	Penalty score in SL (0-5)	Competitive Level (1-6)
Height (cm)		
Weight (kg)	0.580**	
Triceps skinfold (mm)	0.590**	-0.387*
Subscapular skinfold (mm)	0.592**	
Abdominal skinfold (mm)	0.645**	-0.435*
Supra-iliac skinfold (mm)	0.627**	-0.438*
BMI (kg/m ²)	0.628**	-0.433*
Sum of skinfolds (mm)	0.643**	-0.405*
Take-off total time (s)	0.619**	-0.577**
Flight total time (s)	-0.596**	0.636**
Maximum articular amplitude total time (s)		
Forward ankle extension (°)	-0.737**	0.782**
Backward ankle extension (°)	-0.738**	0.582**
Forward hip flexion (°)	-0.791**	0.614**
Backward hip extension (°)	-0.811**	0.821**
Maximum articular amplitude (°)	-0.902**	0.823**

** p < 0.01; * p < 0.05

DISCUSSION

In this study it has been analyzed the relationship between the observed technical penalties in SL (obtained through an adaptation of the FIG's CoP), the gymnasts' competitive level, their anthropometric characteristics, and the most important angular and temporal variables of the jump. Three relevant aspects have been found: 1) a greater adipose tissue, 2) a low hips amplitude angle and 3) a higher take-off phase time, all of them associated with higher penalties and a lower competitive level.

The primary results of the present work showed that the variables that assess adiposity indirectly (body weight, BMI, skinfolds and the sum of them) have been associated with the execution of SL. A higher body weight has been associated with higher penalty, and therefore, with a worse execution (Table 3). Our results match what various studies claim: body weight is a critical factor to take into account for optimal physical performance in RG (Camargo et al., 2014; Vernetta, Fernández, López-Bedoya, Gómez-Landero, & Oña, 2011). In addition to being a disadvantage to performance, overweight in RG favors the appearance of sports injuries primarily when executing jump skills, since it would be harmful for lower limbs joints (ankles and knees) (Zetaruk, Violan, Zurakowski, Mitchell, & Micheli, 2006). These results are reinforced by the observed association between BMI and SL execution, so that a higher body mass also appears to influence a poor performance. This is consistent with the

investigation of Douda et al. (2008) who claim that having a low BMI seems to be an advantage when skills that require complex movements are performed. These authors also state that in elite gymnasts the 8.5% of the variance in performance is explained by BMI. Furthermore, our results are consistent with those obtained by another research where gymnasts who had higher anthropometric measurements (height, weight...) obtained worse scores in competition (Claessens et al., 1991).

Many of the reviewed studies analyze the adipose component distinguishing it from the total weight or BMI, and emphasizing the relationship between an increased amount of fat tissue and a worse performance of gymnastic skills; these studies are consistent with the observed relationship between the four skinfolds evaluated and the penalty score. A greater amount of subcutaneous fat has been linked to a poorer performance in SL. Other authors have presented similar results before (Claessens et al., 1991, 1999; Romero et al., 2011).

Similarly, the sum of the four skinfolds has also proved to be related to a better execution of SL (Table 3). This is an indirect adiposity index which supposes a more objective assessment in the estimation and control of adiposity index than the BMI (Esparza, 1993). In this study, a low subcutaneous fat index has been related to the best performance of SL, as well as with the highest competitive level. Our results coincide with those works that verify that a low fat percentage in RG athletes is determinant of sports performance (Miletic et al., 2004; Claessens et al., 1991, 1999; Douda et al., 2008). Some of these studies claim that a low fat percentage or subcutaneous fat level is strongly related to gymnasts' performance, defined as the score or classification obtained in competition (Claessens et al., 1991, 1999; Douda et al., 2008). Besides, any RG movement or ability needs to be run efficiently, for which a low volume of adipose tissue is fundamental (Miletic et al., 2004; Miletic & Kostic, 2006). In addition, this study confirms what some authors have already indicated: RG athletes are characterized by having a low fat percentage compared not only to sedentary women of the same age but also to other populations of athletes (Vernetta et al., 2011; Miletic et al., 2004; Menezes & Filho, 2006; Camargo et al., 2014).

Moreover, our results have also demonstrated that adiposity index has been associated with competitive level, so that a greater competitive level is linked with a lower adiposity level. These results coincide with studies which analyze the anthropometric profile of RG highlighting the low fat percentage as fundamental variable (Vernetta et al., 2011; Miletic et al., 2004; Menezes & Filho, 2006; Camargo et al., 2014).

Regarding the evaluated angular variables, another one of the most important results of this study was the importance of ankles joints' extension and hips amplitude in SL. Angles of ankles' maximum extension have been associated with lower penalties and therefore with better performance levels, which indicates and demonstrates the importance of keeping the tiptoes stretched in

gymnastic sports, especially in RG, in order to achieve the required aesthetic in movements (FIG, 2013) and, consequently, better quality and assessment. The maximum amplitude angle between both hips presents a high association with improved jump execution (Figure 1A). This represents: 1) the importance of maximum range of motion possible in the execution of RG specific jump skills, and 2), consequently, the relevance of flexibility in its active-ballistic manifestation in this kind of body difficulties. These results coincide with several authors and works (Mendizábal, 2001; Grande et al., 2008; Rodríguez et al., 2013; Romero et al., 2011; Miletic et al., 2004; Miletic & Kostic, 2006; Volpi da Silva, Lopez, Grillo, Moya, & Matsushigue, 2008).

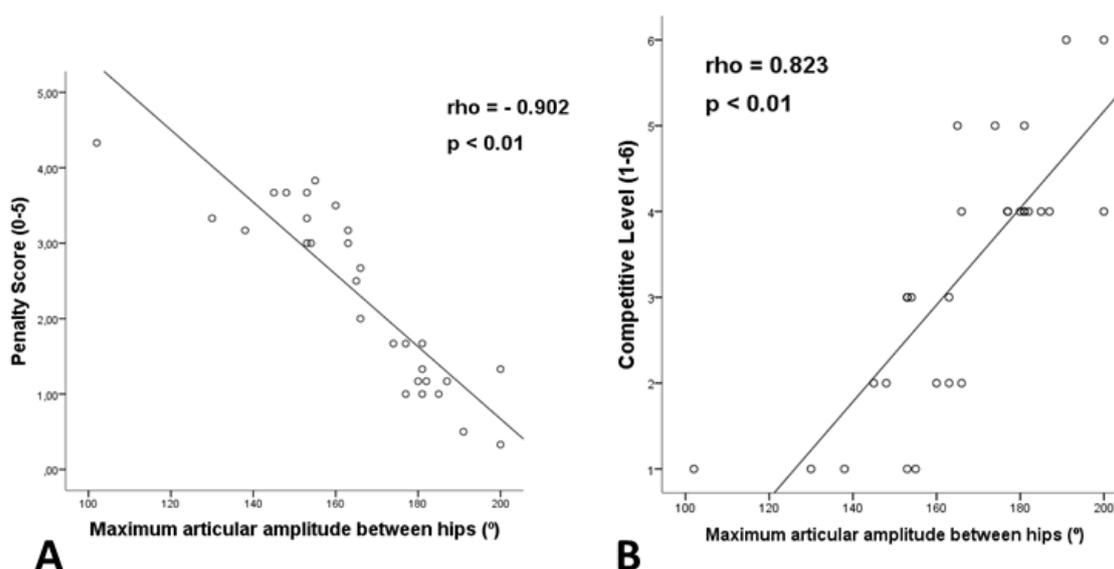


Figure 1.- Correlations between maximum articular amplitude angle and A) Penalty Score in SL, and B) Competitive Level. Data for all subjects ($n = 29$).

On the other hand, this study highlights the importance of take-off and flight phases total time in SL execution. These temporal kinematic variables have been associated with better execution of this body difficulty. According to Hay (1993), in take-off phase explosive strength in lower limbs is required to generate the impulse action (which must be performed with great speed and coordination between the joints involved). In this work it has been observed that the more time a gymnast employs to perform take-off phase, the worse performance level they obtain in jump execution (Figure 2). Moreover, the flight phase duration depends on take-off quality. The better the take-off, the greater chances the gymnast has to perform specific corporal actions and the greater the degree of difficulty that can be achieved with the jump would be (Hay, 1993). Our results are related to the kinematic quantifications regarding the duration of take-off and flight phases in the RG's SL proposed by Grande et al. (2008). Also, our results agree with the statements by Rodríguez et al. (2013), who analyzed the temporal sequence of this same jump comparing the execution of different gymnasts and showing that the take-off and flight total time proved decisive for its proper execution, and also that gymnasts could be

distinguished by their technical level. Ultimately, since CoP establishes a series of requirements for the proper execution of RG jumps (“defined and fixed shape”, and “height sufficient to show the corresponding shape”), the importance of flight phase duration is emphasized, so that so the results we obtained in this phase coincide with what is required by the CoP itself (FIG, 2013). So, the greater the time that gymnast remains in flight phase, the more time she will have to show and maintain or fix the shape of the jump (in this case, split leap), so that the technical quality execution will be greater and the jump better valued.

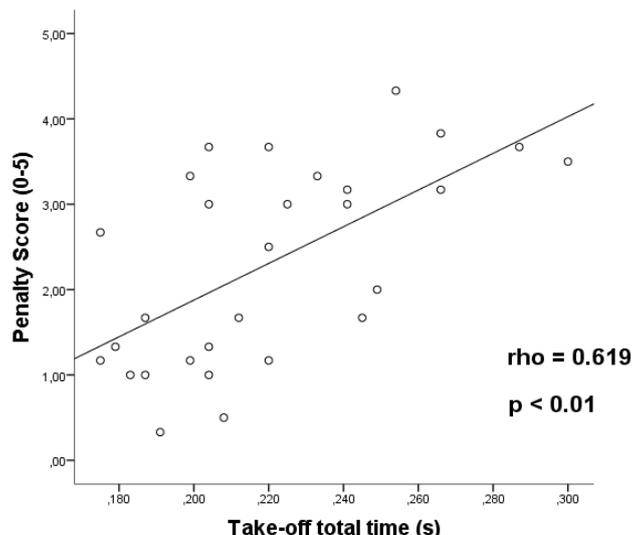


Figure 2.- Take-off total time in relation with penalty score in SL. Data for all subjects (n = 29).

Finally, the last one of the most important results obtained in this study highlights the importance of competitive level as criterion variable, which has demonstrated its relation to the best technical execution in SL. It also presents numerous associations with the analyzed variables, especially with maximum articular amplitude of hips (Figure 1B). So that the observed performance in the evaluated body difficulty (SL) has been associated with a certain competitive level. Our results are similar to those obtained by another research (López & Vernetta, 1997).

CONCLUSIONS

In this study, anthropometric profile of RG (low body weight, low BMI, low subcutaneous fat) has been corroborated and, in addition, lower values of adipose tissue have shown the best results in SL. On the other hand, take-off total time, flight total time, and maximum range of motion (and, therefore, the physical quality of flexibility, particularly in their active-ballistic manifestation) happen to be determinants for the correct execution of SL. Furthermore, the use of filming in high speed (240 fps) has allowed us to visualize those technical details that the coach or the athlete herself would not have appreciated through video cameras of less frequency or a naked eye. Thus, in this work, the importance of keeping the tiptoes stretched in SL performance has been noted.

All these variables that have been associated with the execution of SL lead us to deduce some of the physical requirements demanded by the practice of RG for the execution of jump difficulties: speed, relative strength, explosive-elastic strength and, above all, active-ballistic flexibility. Therefore, through the knowledge about what are the variables that influence the execution of RG body difficulties, we could influence the improvement of these aspects during training processes and enhance the gymnasts' performance: get the highest score or classification in competition.

On the other hand, important relations have been established between the observed SL performance and the gymnasts' competitive level. A certain performance level has been associated with a certain competitive level. However, these results are limited in this work given the heterogeneity of the sample of gymnasts according to their competition levels. Finally, the use of specific jump tests as test battery offers useful and valuable information for RG given that it is a sport with great demand of jump skills. Furthermore, the qualitative assessment of technical execution by the sum of penalties has shown to be a useful tool for the evaluation of performance and gymnasts' competitive level, as it provides useful information for the coach given its objectivity.

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