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USEFULNESS AND METABOLIC IMPLICATIONS OF A 60-SECOND REPEATED JUMPS TEST AS A PREDICTOR OF ACROBATIC JUMPING PERFORMANCE IN GYMNASTS

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ABSTRACT: Gymnastics floor exercises are composed of a set of four to five successive acrobatic jumps usually called a "series". The aims of the study were: 1) to relate the acrobatic gymnastics performance of these series with a repeated jumps test of similar duration (R60), 2) to study the relation between R60 and physiological parameters (heart rate and blood lactate), and the performance obtained in different kinds of jumps, 3) to confirm whether R60, executed without a damped jumping technique, can be considered an anaerobic lactic power test. Twenty male and twenty-four female gymnasts performed three repeated jumps tests for 5 s (R5), 10 s (R10) and 60 s (R60) and vertical jumps, such as drop jumps (DJ), squat jumps (SJ) and countermovement jumps (CMJ). We assessed heart rate (HR) and blood lactate during R10 and R60. The average values of the maximal blood lactate concentration (L_{max}) after R10 (males = 2.5±0.6 mmol · l^{-1}; females = 2.1±0.8 mmol · l^{-1}) confirm that anaerobic glycolysis is not activated to a high level. In R60, the L_{max} (males = 7.5±1.7 mmol · l^{-1}; females = 5.9±2.1 mmol · l^{-1}) that was recorded does not validate R60 as an anaerobic lactic power test. We confirmed the relation between the average power obtained in R60 (R60Wm) and the acrobatic performance on the floor. The inclusion in the multiple regression equation of the best power in DJ and the best flight-contact ratio (FC) in R5 confirms the influence of other non-metabolic components on the variability in R60 performance, at least in gymnasts.

KEY WORDS: heart rate, blood lactate, anaerobic power

INTRODUCTION

In recent decades, an increased demand for anaerobic lactic capacity has been observed in artistic gymnastics, as well as increased values of maximal heart rate (close to 190 beats · min^{-1}) at the end of gymnastics exercise routines [14]. Competition exercises last close to 1 min, and the heart rate (HR) at the end of most of the exercises is about 180 beats · min^{-1}. In addition, many muscle groups work in isometric conditions, with submaximal and maximal muscle forces [15,22]. Consequently, it has been hypothesized that there are considerable requirements of the anaerobic lactic pathway of energy production. Jumping performance has been tested through repeated jumps tasks lasting 1 min [19]. These authors used a force platform and photogrammetry to study modifications in jumping technique due to fatigue. However, they focused on countermovement jumps rather than reactive jumps. Reactive jumps are much more specific to gymnastics, bearing in mind the succession of acrobatics in the floor exercise. The French Gymnastics Federation [8] used a very similar test to ours with a "reactive rebound jump", as the subject was instructed to: 1) minimize knee flexion and extension and, as consequence, shorten the contact time, 2) maximize ankle participation, 3) freely use the arms to balance during the jumps, and 3) be "stiff" to minimize the flexion and extension of the hip. This overall technique was described by Bosco [3], who clarified that the repeated jumps test could be done in both ways: 1) using countermovement jumps in which dampening between each jump is clearly observed; 2) using a reactive rebound jump (RRJ), which is very similar to the drop jump (DJ) technique, known in other studies as the "bounced jump" [2], the "jump for height-time" [26], or the "quick jump" [10]. We chose the second method, as we wanted to replicate gymnasts' natural jumping technique during the floor exercise. Bosco [3] reported that the damped jump technique would produce a much higher energy demand than the RRJ technique and supposedly higher blood lactate concentration and higher HR, among other metabolic factors. Some authors classify as anaerobic alactic power efforts those whose maximum intensity is accomplished in no more than 10 s. Anaerobic lactic power efforts can be classified as those of maximal or submaximal intensity accomplished in 30–60 s [6,9]. We performed two RRJ jumping assessments of 10 s and 60 s to prove the outlined hypothesis, considering the importance of this kind of muscle action in gymnastics and particularly in the floor exercise and the vault. Due to the duration of floor routines (from 60 to 90 s), we considered that the average power recorded in the RRJ in 60 s would be the best predictor of acrobatic performance. Some repeated jumps tests with a certain duration (from 5 s to 60 s) have been used before in the literature [3,19]. However, no studies have combined three different approaches as in the present study: 1) to verify the supposedly strong relationship between acrobatic jumping performance in the floor exercise and the average mechanical power obtained in R60, 2) to assess simultaneously physiological responses, such as HR and blood lactate concentration, and field performance responses in RRJs including the flight time (FT), the contact time (CT), the flight-contact time ratio (FC) and the estimated mechanical power, and 3) to study the relationship between the parameters measured in R60 and the many different types of isolated jumps with or without countermovement.

MATERIALS AND METHODS

Subjects. Forty-four gymnasts (20 men and 24 women) volunteered for this study. The average age was 17.8±4.7 years for men and 11±1.9 years for women. The selection criterion was a minimum of 22 hours' training per week. The study was approved by the ethics committee of clinical research of the Catalan Sport Administration and written consent was given by all participants and/or guardians.

Jumping assessment

To record the jumps we used the Ergo Jump Bosco System® and a contact mat of 1.20 m x 80 cm. The jumping test was adapted to the protocol described by Bosco et al. [3,4,5,7]. It included a squat jump (SJ) with a progressive overload of 0, 25, 50, 75 and 100% of body mass, a countermovement jump (CMJ), a drop jump (DJ) from 20, 40, 60, 80 and 100 cm drop height, and a repeated jumps test for 5 s (R5), 10 s (R10) and 60 s (R60). To make the test as specific as possible to the sport of gymnastics, we told the gymnasts to carry out R5, R10 and R60 in the following way: to jump as high as possible in each jump, but with the shortest contact time (CT) and the free use of the arms. This protocol is different to the one used by Bosco [3] in R60, in which the subject was told to make repeated jumps like CMJ, with a knee flexion angle of 90º in each jump, during the entire duration of the test. In our study, we tried to remain as close as possible to the natural jumping movement of the gymnasts. This led to successive rebound jumps with a technique very close to the "bounce drop jump" (BDJ) [2], "DJ for height-time" (DJ-H/t) [26] or the "quick drop jump" (QDJ) [10].

At the end of a repeated reactive jump test over the contact mat we downloaded the contact time (CT) and flight time (FT) for each jump executed during the prescribed duration. The mechanical power was calculated using FT and CT, according to the formulae proposed by Bosco et al. [7] (Equation 1). This equation carries certain known biases, as shown by Hatze [12]. However, this expression is used in a very strict condition, as stated by Arampatzis et al. [1].

$$W = \frac{g^2 \cdot FT_{tot} \cdot T_{tot}}{4n \cdot CT_{tot}}$$

where n = number of jumps
FT_{tot} = total flight time ($FT_{tot} = \sum Ft_n$)
CT_{tot} = total contact time ($CTtot = \sum Ct_n$)
T_{tot} = total duration of the test
g = acceleration of gravity ($9.81\ m \cdot s^{-2}$)

Equation 1. The total duration (T_{tot}) of the repeated jumps tests was 5, 10 and 60 s in our study.

Metabolic measurements

The Polar RS400 heart rate monitor and HR ANALYSIS software were used to record heart rate. Venous blood lactate was analyzed using a photoenzymatic method (Boehringer Mannheim, RFA) and methodology presented by Rodríguez et al. [20].

The heart rate monitors were connected to each gymnast at least 1 min before the first jump series ended until all blood samples had been collected. The blood samples for the lactate trial were collected at 1, 3 and 5 minutes of recovery after R10 and during minutes 1, 3, 5, 7, 10 and 12 after R60.

Acrobatic performance categories

In this study, we considered as a measure of acrobatic performance a score from 1 to 5 (from lower to higher respectively). The scores were given by the Federation coaches of the men's artistic gymnastics (MAG) and women's artistic gymnastics (WAG) teams. The score depended on the raw score obtained in competition, and on the level of aerial difficulty and jump amplitude of the acrobatic series performed separately by each gymnast and included in their competitive routine (e.g. rondade + flic-flac + double extended somersault). This methodological approach was adopted as the marking system varied between sexes and categories, and not all gymnasts belonged to the same category. In fact, three consecutive categories (juvenile, junior and senior) were included in the male and female samples. In other words, a direct comparison using only the floor competition scores would not have been appropriate.

Parameters

The following parameters were used in this study: age (months), body mass (kg), height (cm), flight time (FT, ms), contact time (CT, ms), power (W, $W \cdot kg^{-1}$), heart rate (HR, $beats \cdot min^{-1}$), and venous blood lactate concentration (L, $mmol \cdot l^{-1}$). From R5 and DJ, we extracted the flight-contact time ratio (FC) of the best jump registered.

Statistics

Because of the great differences in age between males and females, we decided to carry out an independent analysis for each sex, rather than directly comparing performance between sexes. The Shapiro-Wilk test was used to confirm the normal distribution of the male and female sample.

To address Aim 1, we used Spearman's correlation to check the relations between the categorical performance score and the R60 jumping parameters. With respect to Aim 2, we used descriptive statistics based on heart rate and blood lactate to confirm whether R10 and R60 can be considered an anaerobic alactic power test and an anaerobic lactic power test respectively, from a physiological perspective. Finally, when the overall duration of the R60 test was divided into 6 lots of 10 s, we used repeated measures ANOVAs with the lot (from 1 to 6) as the repeated factor to study the trends of FT, CT, FC and power during the R60 test. Post-hoc analyses were implemented when appropriate with the Sidak adjustment for multiple comparisons. For Aim 3, we used a multiple regression analysis (stepwise method) to obtain the average estimated power in R60 (R60Wm) as the dependent variable. The heart rate, blood lactate concentration, age, body mass, and jumping performance variables obtained in SJ, CMJ and DJ were used as independent variables. Before we included the jumping performance parameters in the multiple regression analysis, we proceeded in the following order: 1) we categorized (n=6) the jumping performance parameters according to their nature, i.e. FT, CT, FC, power, HR_{max} and L_{max} constituted six different groups of parameters; 2) we selected from within each group those parameters with the highest Pearson correlations, 3) we processed the multiple regression and verified collinearity and homoscedasticity (with the Durbin Watson test). The Cochrane-Orcutt method was used if the Durbin Watson value was too far from 2. The level of significance (p values) was set at 0.05 for all statistics.

RESULTS

An analysis of the relations between the categorical performance score in floor acrobatics and the parameters obtained in the jumping test showed a very significant correlation (MAG=0.98; WAG=0.97; $p \leq 0.001$) between the estimated average power in R60 (R60Wm) and the score given by the men's and women's coaches. The relation between the score, the best power in DJ (MAG=0.54; WAG= 0.69; $p \leq 0.001$) and the maximal blood lactate concentration (L_{max}; MAG and WAG=0.54; $p \leq 0.001$) was also notable. Finally, in men more than in women, a relationship was found between the SJ with an overload equivalent to the body mass (SJ100) and the score (MAG=0.64; WAG= 0.42; $p \leq 0.001$).

The second aim was focused on the descriptive analysis of the repeated RRJ jumps tests (R10 and particularly R60). Descriptive data are presented in Table 1 and Figure 1. L_{max} was low in both

TABLE 1. DESCRIPTIVE DATA FROM THE 10- AND 60-SECOND REPEATED JUMPS TEST (R10 AND R60 RESPECTIVELY). WOMEN (WAG) AND MEN (MAG) GYMNASTS

Parameter	Repetitive Jumping test	Women (WAG; n= 24)	Men (MAG; N = 20)
Average Power ($W \cdot kg^{-1}$)	R10	36.23 ± 25.5 (max= 70.4)	61.04 ± 6.8 (max= 78.4)
	R60	30.87 ± 21.7 (max= 59.9)	51.74 ± 6.01 (max= 67.4)
Max. Lactatemia (L_{max}, $mmol \cdot l^{-1}$)	R10 (min 3 recovery)	2.1 ± 0.8 (max= 4.5)	2.5 ± 0.6 (max= 3.5)
	R60 (min 5 recovery)	5.9 ± 2.1 (max= 10.42)	7.5 ± 1.7 (max= 10.8)
Max. Heart rate (HR, $beats \cdot min^{-1}$)	R10	167 ± 45 (max= 235)	147 ± 16 (max= 185)
	R60	197 ± 18 (max= 234)	178 ± 8 (max= 195)

TABLE 2. REPEATED MEASURES ANOVAS WITH LOT (FROM 1 TO 6) AS THE REPEATED FACTOR TO STUDY THE TRENDS OF FLIGHT TIME (FT), CONTACT TIME (CT), FLIGHT CONTACT RATIO (FC) AND POWER DURING THE R60 TEST. ANALYSIS IS DONE SEPARATELY FOR WOMEN (WAG) AND MEN (MAG) GYMNASTS

Parameter		Effect F	Effect df	Effect p	Trend (lineal) F	Trend (lineal) df	Trend (lineal) p
FT	WAG	39.57	5, 23	≤ 0.001	83.21	1, 23	≤ 0.001
	MAG	16.50	5, 19	≤ 0.001	30.33	1, 19	≤ 0.001
CT	WAG	1.45	5, 23	ns	1.95	1, 23	ns
	MAG	1.04	5, 19		1.50	1, 19	
FC	WAG	15.44	5, 23	≤ 0.001	32.52	1, 23	≤ 0.001
	MAG	15.12	5, 19	≤ 0.001	28.69	1, 19	≤ 0.001
Power	WAG	25.92	5, 23	≤ 0.001	52.34	1, 23	≤ 0.001
	MAG	19.69	5, 19	≤ 0.001	35.12	1, 19	≤ 0.001

tests and sexes, whereas HR_{max} was high even after the R10 test (Table 1). For the flight time (FT), we observed in both sexes a significant linear negative trend throughout the R60 test, whereas the contact time (CT) did not change (Table 2). The different trends observed in FT and CT gave as a result a progressive decrease in the FC ratio and the estimated average power (Table 2, Figure 1).

Once we had confirmed that there was a significant relationship between R60Wm and the score in floor acrobatics in both sexes, and assessed the metabolic and field performance responses in RRJs, we focused on Aim 3. To do that, we assessed which of the parameters collected in the set of single vertical jumps with and without a stretch shortening cycle (SSC) had the strongest relation with R60Wm.

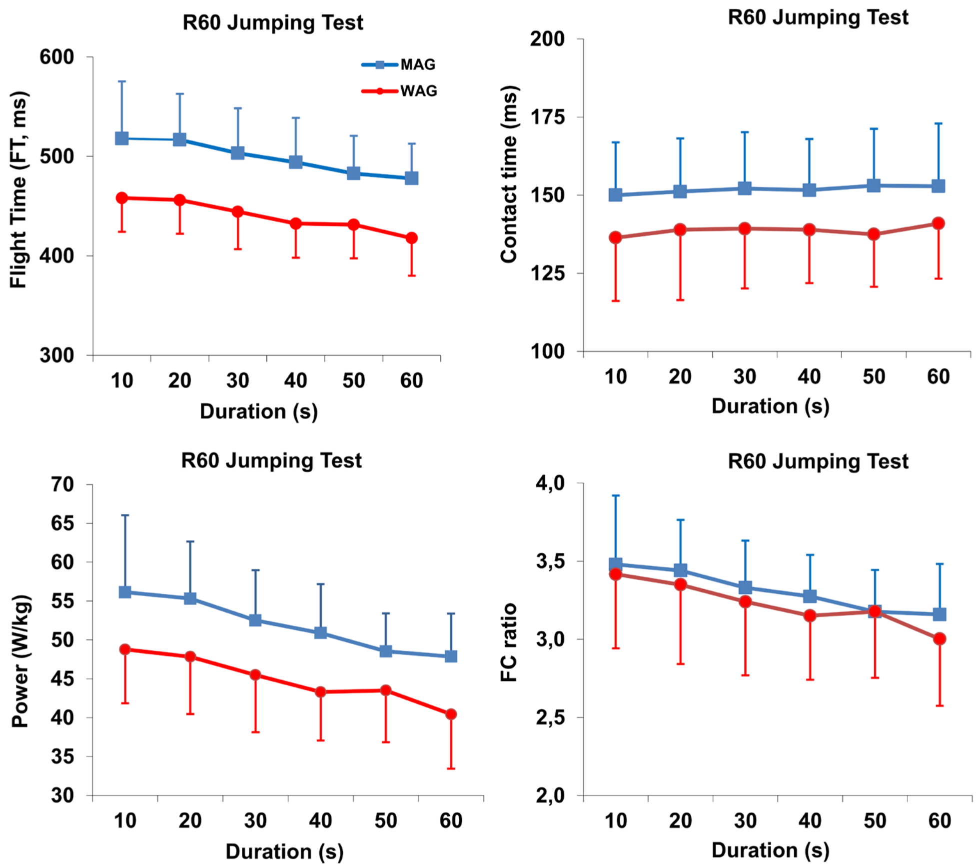

FIG. 1. TIME COURSE AND MAGNITUDE OF CHANGES OF THE ESTIMATED MECHANICAL POWER, FC RATIO (FLIGHT TIME/CONTACT TIME), FLIGHT TIME (FT), AND CONTACT TIME (CT) DURING THE 60-SECOND REPEATED JUMPS TEST (R60). WAG = WOMEN'S ARTISTIC GYMNASTICS; MAG = MEN'S ARTISTIC GYMNASTICS

TABLE 3. PEARSON CORRELATION BETWEEN THE AVERAGE ESTIMATED POWER OBTAINED IN R60 JUMPING TEST (R60WM) AND THE GROUPS OF PARAMETERS (FT, FC, POWER) COLLECTED FROM THE SINGLE VERTICAL JUMPS (SJ, CMJ, DJ), MAXIMAL BLOOD LACTATE (LMAX) AND MAXIMAL HEART RATE (HR)

Parameters category	Females (n = 24)		Males (n = 20)	
	Test	Correlation (r)	Test	Correlation (r)
Flight Time (FT, ms)	DJ80	0.58	SJ100	0.61
			DJ40	0.56
			CMJ	0.56
FC ratio (FC)	DJ20	0.64	DJ60	0.59
	R5	0.69	R5	0.64
Power ($W \cdot kg^{-1}$)	DJ100	0.69	DJ80	0.61
	BDJ	0.69	BDJ	0.63
Max. Lactatemia (L_{max}, $mmol \cdot l^{-1}$)	R60	0.60	R60	0.60
Max. Heart rate (HR, $beats \cdot min^{-1}$)	R60	-0.61	R60	-0.61

Note: All r values reported in the table have $p \leq 0.001$.

Once we had grouped the jumping performance (n=3; FT, FC and power) and the physiological parameters (n=2; HR_{max} and L_{max}) according to their nature, we selected from within each group those parameters with the higher Pearson correlations (Table 3).

In the multiple regression analysis, we observed that 65% of the variance comes from the best power in DJ at any of the 5 heights (BDJ), the best FC ratio of R5, and the L_{max} and HR_{max} recorded in R60 (Rm = 0.83, Rm2 = 0.65, p≤0.00001) (Equation 2):

$$R60Wm = 0.46\ BDJw + 1.6\ L_{max} - 0.7\ HR_{max} + 0.58\ FCR5 + 21.32$$

where:

BDJw	=	the best mechanical power obtained in a drop from any of the 5 heights
FCR5	=	the best FC ratio obtained in R5
L_{max}	=	the maximum blood lactate concentration obtained during recovery from R60
HR_{max}	=	the maximum heart rate registered at the end of R60

Equation 2. Multiple regression analysis. The average estimated mechanical power in R60 (R60Wm) is the dependent parameter.

DISCUSSION

The strong correlation found in both sexes between the average mechanical power in R60 (R60Wm) and the categorical score given by the coach of the respective events (WAG and MAG) supports the general understanding that a competitive gymnast must generate and maintain high levels of net impulse and power during their routines [13]. This is particularly true if the movement used during the assessment is performed with a technique very close to that required during a series of acrobatics in gymnastics floor routines. This is why we chose the bounced jumping technique in R5, R10 and R60 [2,10,26], instead of the repeated CMJ with dampening between each jump [3,22]. Gymnasts usually begin their floor routine with the series that is most difficult acrobatically and try to finish their exercise with a series that is comparable to that used at the beginning. To achieve this goal, they must be able to produce a similar amount of net impulse and power throughout (MAG: 50–70 s; WAG: max 90 s) their routine. Our results confirm the close relationship between R60Wm and the requirements explained above.

Before we confirm whether R60 can be considered an anaerobic lactic test (Aim 2), we should discuss the R60 descriptive data. Some trends were observed in the parameters recorded using the contact mat (FT, CT, FC and power). In particular, CT was maintained throughout R60. Our results do not support those of Gollhofer et al. [11], who observed an increase in CT due chiefly to the rise in the concentric phase of the stretch shortening cycle (SSC). This discrepancy could be explained by the fact that different segments were studied (forearm extensors instead of leg extensors, as in our study). It could also be due to the bounced jumping technique used in our study, which requires more stiffness than the SSC and an elastic component that is more characteristic of damped jumps with greater knee flexion and extensions [2,10,26]. As we know the mathematical expressions of the FC ratio and the estimated mechanical power, their progressive decrease in both sexes is due to the FT decrease without the combined effect of the CT increase. During R60, repeated attempts to absorb the shock followed by concentric contractions could eventually be so tiring that the muscle would gradually adjust its tension. According to previous studies [11,16], this adjustment could be characterized by a gradual decrease in knee flexion and higher initial peak force produced by the subsequent more pronounced initial drop of force.

The HR_{max} registered in R60 (~197 beats·min^{-1} for WAG and ~178 beats·min^{-1} for MAG) admit comparison against maximum values registered after a competitive exercise during training sessions [14], and confirmed the maximal demands on the cardiac pump. The maximal HR values reported in the present study (Table 1) should be interpreted with caution. On one hand, we have some arguments to believe that those HR values could be verified. After a review of the literature, Rowland [21] reported very high HR_{max} through growing ages, suggesting that peak HR_{max} values above 211 beats·min^{-1} cannot be excluded in young subjects. On the other hand, as suggested by Schawaberg [25], it is possible to reach very high values of HR without there necessarily being a proportionate demand of physical stress or exercise intensity. Meanwhile, other authors [17] have reported in gymnasts that significantly different levels of stress do not necessarily result in different HR values. Overall, it seems that particularly tests of maximal intensity from the very beginning of the assessment, as in this study, solicit a combination of psychological stress, emotional activation strategies and arousal levels which induce higher HR values not explained strictly by the workload and metabolic demand measured during such assessment. This kind of situation is very common in gymnastics, just before the beginning of a competitive routine [13].

The L_{max} values obtained in our study are lower than the values obtained by Bosco [3] in a jumping test of similar duration but different execution, as explained in the method section. Nevertheless, our L_{max} values confirm Bosco's conclusion that in 60 s repeated jumps tests it is difficult to observe L_{max} values above 10 mmol·l^{-1} [3]. The maximum blood lactate concentration during recovery in a supramaximal effort is interrelated directly to the quantity of energy freed by the blood lactate [9].

The jumping technique adopted in the repeated jumps test with very short CT led us to assume that our gymnasts had a small knee flexion and extension angle (no more than 60º, considering 180º as full extension), according to Bosco and Komi [4]. A reduced knee flexion angle (±50º) during repeated jumps can reduce energy expenditure by about 30% in comparison to wider knee angles (±90º). This is due to elastic energy reutilization, electrical muscle activity and the biomechanical characteristics of the knee joint [24]. Even though the gymnasts in our study used reduced knee flexion angles, the participation of the arms could increase energy expenditure and, consequently, the release of lactate. This could explain the quite similar lactate values (especially the maximal ones), in spite of the different movement pattern used in our study and that of Bosco [3].

Nevertheless, the moderate concentration of blood lactate in R60 suggests that even though glycolysis is activated, it is not high. Bearing in mind the jumping technique used in our study, it is questionable whether R60 is a valid anaerobic lactic power test. This assertion is compatible with the previously described fact that the mechanical power in R60 is closely interrelated with blood lactate concentration, which is a relevant factor for performance in such assessments.

The third aim was to find out whether the wide sort of single vertical jumps assessed with a contact mat according to the consulted literature [3,4,5,7] could explain R60Wm. In the multiple regression analysis, we found that none of the flight time (FT) parameters were included in the equation. This observation could be partially explained by a previous study in which flight time (FT) was the discriminating factor that was least able to distinguish gymnasts' DJ performances [18]. In accordance with these authors, the best estimated mechanical power in DJ, considered by Marina et al. [18] as one of the factors that better distinguish gymnasts' jumping performances, was precisely the factor that had the strongest influence on R60Wm and the first parameter introduced in the multiple regression model. As gymnasts perform their jumps with very short contact times (CT) [18], the FC ratio must be an important parameter to take into account. The inclusion of the FC ratio in R5 (FCR5) as the second and last non-physiological parameter in the multiple regression model confirms the importance of jumping as high as possible but with short CTs. The inclusion of FCR5 instead of other FC ratios from DJs can be explained by the fact that the only environmental difference between R5 and R60 is the duration, whereas the best DJ is usually performed from a wooden plinth at higher drop heights, usually from 40 to 60 cm, according to Marina et al. [18].

The correlation between mechanical power and the two physiological parameters of maximal heart rate (HR_{max}) and blood lactate (L_{max}) in R60 can be understood as an inverse relationship between the kinetic activation of the oxygen transportation system (and therefore the acceleration of HR) and the activation of anaerobic glycolysis. This results in higher concentrations of blood lactate. The high HR_{max} obtained in R60 could be explained by a considerable increase in peripheral resistance rather than high oxygen consumption. To confirm this assumption, future research could directly measure oxygen consumption in R60. The inclusion of R60 L_{max} in the multiple regression model suggests that the activation of the glycolytic pathway is a determining factor, despite the moderate L_{max} obtained in R60.

CONCLUSIONS

The average power in R60 (R60Wm) proved to be strongly related to the categorical gymnastics acrobatic performance assessed by highly qualified gymnastics coaches. R10 is confirmed as an anaerobic alactic jumping test, whereas R60 was found to be an anaerobic lactic power test. Haemodynamic factors, more than metabolic ones, can probably explain the intense tachycardia induced by the effort in both tests. Other non-metabolic factors, such as the estimated mechanical power and FC ratio in plyometric jumps, could have a greater influence on R60 performance.

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