Relationship of maximal aerobic power and muscular strength with the running economy in endurance athletes*

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ABSTRACT

The objective of this study was to analyze the relationship of maximal aerobic power and the muscular strength (maximal isotonic strength and vertical jump explosive power) with the running economy (RE) in endurance athletes. Twenty-six male runners (27.9 ± 6.4 years; 62.7 ± 4.3 kg; 168.6 ± 6.1 cm; 6.6 ± 3.1% of body fat) performed in different days the following tests: a) incremental test to determine the maximal oxygen uptake ($\dot{V}O_2max$) and the intensity corresponding to the $\dot{V}O_2max$ ($I\dot{V}O_2max$); b) constant-velocity treadmill run to determine RE; c) 1-RM test in the leg press and; d) maximal vertical jump test (VJ). $\dot{V}O_2max$ (63.8 ± 8.3 ml/kg/min) was significantly correlated ($r = 0.63$; $p < 0.05$) with RE (48.0 ± 6.6 ml/kg/min). However, the $I\dot{V}O_2max$ (18.7 ± 1.1 km/h), the maximal isotonic strength (230.3 ± 41.2 kg) and the VJ (30.8 ± 3.8 cm) were not significantly correlated with RE. One concludes that the maximal aerobic power can explain in part the inter-individual RE variability in endurance athletes. However, maximal isotonic strength and explosive strength seem not to be associated with RE values observed in this group of athletes.

Key words: Running economy. Maximal oxygen uptake. Muscular strength.

INTRODUCTION

The running economy (RE) may be defined as the oxygen cost ($\dot{V}O_2$) for a given treadmill run velocity(1). Some authors have shown a quite high inter-individual RE variability (> 15%) even among well-trained individuals, presenting similar maximal oxygen uptake values ($\dot{V}O_2max$)(2). A better RE (i.e., a lower $\dot{V}O_2$ for a given running velocity) may be worthwhile, especially in endurance events, once it will allow a lower fractional $\dot{V}O_2max$ utilization for any submaximal intensity exercise. In well-controlled experimental conditions, the RE presents good reproducibility with intra-individual variation from 1.5 to 5%(3).

Part of the RE variability has been associated to factors such as anthropometrical (mass distribution in segments), physiological (type of muscular fiber), biomechanical and technical(4). Interestingly, some studies performed in running(5,6) and cycling(7) have verified inverse relation of $\dot{V}O_2max$ with RE (running) and efficiency (cycling). These results have generated a series of discussions(8,9), indicating the need of further studies to investigate this relation ($\dot{V}O_2max$ x RE) in athletes with different performance levels.

The high-intensity aerobic interval training (5 x ~ 2.5 min at 100% $\dot{V}O_2max$) with one or two weekly sessions performed during four weeks may be sufficient to improve RE of distance runners(10,11). Likewise, the addition of the explosive-strength training (plyometric training) during nine weeks improved the RE (8%) and the performance (3%) of runners in the distance of 5 km(12). The neural adaptation (higher neural activation of the motor units) and the increase on the capacity of using the elastic energy stored in the muscle-tendon set have been pointed as probable mechanisms that may determine the RE improvement with plyometric training(13). Thus, one could hypothesize that the neuromuscular characteristics would explain in part the inter-individual RE variability in trained runners. However, to our knowledge, no study has investigated the relationship between muscular strength and RE in athletes. In this context, the objective of this study was to analyze the relationship of maximal aerobic power ($\dot{V}O_2max$) and muscular strength (maximal isotonic strength and vertical jump explosive power) with the running economy (RE) in endurance athletes.

MATERIAL AND METHODS

Subjects

Twenty-six male runners (27.9 ± 6.4 years; 62.7 ± 4.3 kg; 168.6 ± 6.1 cm; 6.6 ± 3.1% of body fat) specialized in middle-distance and distance running participated in this study. All runners trained six days a week with weekly volume ranging from 70 and 90 km. All participants were informed of procedures and implications (risks and benefits) through a written and explained consent form. The protocol was approved by the Ethics Research Committee of the institution where the experiment was conducted (Protocol 906).

Experimental design

All individuals studied attended the laboratory in four different opportunities with interval of five to seven days between the first and the last attendance. The individuals were told not to train exhaustively in the day preceding the evaluation and to attend the test day well fed and hydrated.

At the first attendance, the individuals were submitted to incremental protocol in treadmill to determine the maximal oxygen uptake ($\dot{V}O_2max$) and the intensity corresponding to the $\dot{V}O_2max$ ($I\dot{V}O_2max$), besides being submitted to anthropometrical measurements. At the second day, the athletes were submitted to a test to determine the RE. At the third and fourth day, a test was randomly performed to evaluate the vertical jump (VJ) explosive power and other test to determine the maximal isotonic strength.

Determination of $\dot{V}O_2max$ and $I\dot{V}O_2max$

$\dot{V}O_2max$ was determined by using an incremental protocol in treadmill (*Imbramed Millenuim Super ATL*). The initial load was of 12 km/h (1% of inclination) with increments of 1 km/h each three minutes until voluntary exhaustion. An interval of 30 seconds for blood collecting from earlobe was given between each stage for blood lactate evaluation. The $\dot{V}O_2$ was measured through respiration during the entire protocol from the gas exhaled (K4 b^2, *Cosmed*) and data were reduced into averages of 15 s. The $\dot{V}O_2max$ was considered as the highest valued obtained during test in these 15-seconds intervals. To consider that individuals have reached $\dot{V}O_2max$ during the test, the criteria proposed by Taylor *et al.*(14) and Lacour

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et al.(15) were adopted. The I$\dot{V}O_2$max was the lowest velocity in which $\dot{V}O_2$max was reached and maintained for at least one minute. If $\dot{V}O_2$max reached during the stage could not be maintained for at least one minute, the velocity of the previous stage was adopted as I$\dot{V}O_2$max(10). The blood lactate was determined through an electrochemical method (*YSL 2300 STAT*).

Test to determine the running economy (RE)

The runners performed a warm-up exercise for seven minutes at 12 km/h followed by eight more minutes at 14 km/h. The $\dot{V}O_2$ was measured between the 6th and 7th minute at 14 km/h, serving as reference for the athlete's RE, which was defined as the relationship between $\dot{V}O_2$ and the running velocity(1).

Determination of the vertical jump explosive power

The subjects were submitted to VJ test to determine the elevation of the center of gravity in relation to the ground. The elevation of the body's center of gravity was determined by means of the jump test equipment (version 1.1). The equipment's validity had been previously determined in comparison to a strength platform(16). A vertical jump technique was used with a preparation movement in which the athlete is allowed to perform the eccentric phase followed by the concentric phase of the movement. The individual starts the movement in standing position with hands fixed at the waistline and feet parallel and separated at approximately the shoulders' width and performs a movement downwards inflecting hip, knees and ankles joints. The transition from the first phase (descendent) to the second phase (ascendant) occurs in a continuous movement in which the joints are extended the fastest as possible. Thus, the mechanisms associated to the stretching-shortening muscular cycle may be used. This jump is applied to determine the lower limbs explosive power level (vertical impulsion).

All individuals performed 10-15 minutes warm-up exercises, which was composed of stretching exercises and some jumps. Then the athletes performed five jumps in the jump test with 30 seconds of interval between each jump. The maximal height was considered as the arithmetic average of the three best jumps.

Protocol to determine the maximal isotonic strength

The maximal isotonic strength was determined using a protocol of maximal load (1-RM) obtained during knees flexion and extension by means of a fitness specific device (leg press 45°). The athletes performed warm-up exercises composed of stretching and three series with 15 repetitions (30% of the body mass) with 60 seconds interval between each series. After this procedure, the maximal isotonic strength was determined as the maximal load in which the athletes performed the full knees flexion and extension reaching the angle of 90° during the eccentric phase. Up to five attempts were performed at the same day with five minutes of interval between each repetition(17).

Statistical analysis

Data are expressed as average ± standard deviation (SD). The relationship of RE (dependent variable) with $\dot{V}O_2$max, I$\dot{V}O_2$max, maximal isotonic strength and VJ (independent variables) was analyzed through the Pearson correlation test. The significance level of $p \leq 0.05$ was adopted in all tests.

RESULTS

Table 1 shows the values of $\dot{V}O_2$max, I$\dot{V}O_2$max, RE, maximal load and the jump maximal height.

The $\dot{V}O_2$max was significantly associated with RE ($r = 0.63$; $p < 0.05$) (figure 1). The I$\dot{V}O_2$max ($r = -0.12$; $p > 0.05$), the jump maximal height ($r = 0.13$; $p > 0.05$), maximal load expressed in absolute values ($r = -0.07$; $p > 0.05$) and values relative to the body mass ($r = 0.04$; $p > 0.05$) were not significantly correlated with RE.

TABLE 1
Average values ± SD of maximal oxygen uptake ($\dot{V}O_2$max) and its respective intensity (I$\dot{V}O_2$max) of the running economy (RE), maximal load (1 RM) and jump maximal height (VJ). N = 26

	$\dot{V}O_2$max (ml/kg/min)	I$\dot{V}O_2$max (km/h)	RE (ml/kg/min)	1 RM (kg)	VJ (cm)
Average	63.8	18.7	48.0	230.3	30.8
SD	8.3	1.1	6.6	41.2	3.8

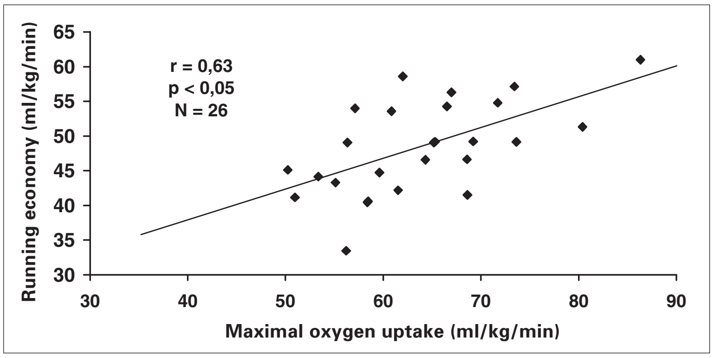

***Fig. 1** – Relationship between maximal oxygen uptake and running economy*

DISCUSSION

The main objective of this study was to analyze the relationship between maximal aerobic power ($\dot{V}O_2$max) and muscular strength (maximal isotonic strength and vertical jump explosive power) with RE in endurance athletes. According to studies previously conducted(5,6), it is verified that the maximal aerobic power explains in part the inter-individual RE variations in endurance athletes. However, the maximal isotonic strength and the explosive power seem not to be associated with RE values in this group of athletes.

The RE determination in athletes who participate in events with aerobic prevalence has shown to be more and more important. In highly-trained athletes with homogeneous values of $\dot{V}O_2$max, the prediction of the aerobic performance(13) and the control of the high-intensity aerobic training effects(11) or the addition of the plyometric training(12) may be mainly performed with the RE evaluation. Thus, studies conducted to understand factors (physiological, anthropometrical and biomechanical) that affect the RE are more and more necessary.

The RE values of our subjects are similar to values found in other studies that analyzed middle-distance and distance runners with velocities similar to the present study(10,18). It is important to emphasize that in well-controlled experimental conditions the RE presents good reproducibility, showing intra-individual variation of 1.5 to 5%(3). Furthermore, the velocity (14 km/h) in which the RE test was conducted corresponded to 75% of the $\dot{V}O_2$max on average, discarding the possibility of the existance of $\dot{V}O_2$ slow component which could influence the RE values.

Pate *et al.*(6) analyzed a group of recreational runners (n = 188) and found low correlation ($r = 0.26$), but statistically significant ($p < 0.001$) between $\dot{V}O_2$max and submaximal $\dot{V}O_2$ during running with velocity of 9.6 km/h. Similarly to our study, Morgan and Daniels(5) verified moderate correlation ($r = 0.59$; $p < 0.01$) between $\dot{V}O_2$max and RE in well-trained runners ($\dot{V}O_2$max = 75 ml/kg/min). Pate *et al.*(6) propose that part of the association between RE and $\dot{V}O_2$max may be explained by the utilization of different energetic substrates. In their study, the authors found inverse relationship ($r = -0.35$; $p = 0.002$) between $\dot{V}O_2$max and R (respiratory quotient) obtained during submaximal running, indicating that individuals with higher $\dot{V}O_2$max used a higher fat percentile in this condition. As the fat metabolism requires a higher amount of O_2 per energy unit produced, the authors propose that runners with higher $\dot{V}O_2$max need higher submaximal $\dot{V}O_2$ during running. It is important to emphasize that in this study, the running intensity (9.6 km/h) corresponded to 68% of the $\dot{V}O_2$max on average, presenting, however, large individual variation (46-91% of the $\dot{V}O_2$max). On the other hand, in the investigation conducted by Morgan and Daniels(5), the variation of the running relative intensity was far lower (3-4%), making R and hence the utilization of substrates to be responsible for the small RE variability (< 4%), questioning the influence of the participation of this factor on the RE in trained individuals.

For this reason, Morgan and Daniels(5) proposed that the relationship between $\dot{V}O_2$max and RE could be explained by differences in the body mass distributions in segments, particularly in lower limbs. Considering this hypothesis, the authors also propose that the subjects who present a higher percentile of their body mass in lower limbs would present higher $\dot{V}O_2$max, considering a higher active muscular mass during running. In this context, these subjects may present higher submaximal $\dot{V}O_2$ to accelerate their lower limbs, thus presenting a higher energetic expenditure. It is important emphasizing that this hypothesis has not yet been adequately tested.

In cycling, where the effects of the body mass on the energetic expenditure are less important, especially when the body composition variation is small, Lucia *et al.*(7) also found significant relationship ($r = 0.65$; $p < 0.05$) between submaximal energetic expenditure and $\dot{V}O_2$max in elite cyclists. Lucia *et al.*(7) proposed that the lowest $\dot{V}O_2$max presented by the high-performance cyclist studied is compensated by their high efficiency, what would end up by generating more homogeneous $I\dot{V}O_2$max values. In other words, the selection imposed by high-level sports would allow cyclists with relatively low $\dot{V}O_2$max values to reach high yielding by presenting higher efficiency. It is important recalling that the $I\dot{V}O_2$max is mainly determined by the interaction between $\dot{V}O_2$max and RE (running) or efficiency (cycling), being better predictive of aerobic performance than $\dot{V}O_2$max or RE alone(19).

Our data seem to corroborate, at least in part, the hypothesis raised by Lucia *et al.*(7). First of all, no significant correlation was verified between $I\dot{V}O_2$max and RE ($r = -0.12$). Second, the $I\dot{V}O_2$max inter-individual variability (6%) was far lower than $\dot{V}O_2$max (13%) and RE (12.5%).

The sarcomer maximal shortening velocity (Vmax) of fiber type II in humans is 3-5 times higher than that found in fiber type I(20). The muscular efficiency, defined as the amount of work performed by the muscular fiber in relation to its energetic expenditure, is higher when the contraction velocity is approximately 1/3 of the Vmax for both types of fiber(20). Thus, when contractions are isometrically performed or performed at low velocities, the fibers type I are more efficient than fibers type II(21). The relationship between the % of the type of muscular fiber and RE yet present contradictory information. Williams and Cavanagh(22) found no correlation between the % of fiber type I and submaximal $\dot{V}O_2$ in runners who presented high RE variability. Likewise, Kyrolainen *et al.*(18) found no significant correlation between the percentile distribution of the different types of fibers and RE in a group of middle-distance runners and RE homogeneous values. On the other hand, Bosco *et al.*(23) found positive correlation ($r = 0.60$; $p < 0.01$) between the % of fiber type II and $\dot{V}O_2$ during submaximal running. The authors propose that fibers type I may hold more elastic energy, reducing the energetic expenditure of the oxidative system.

Some studies have verified that the explosive strength training (plyometric training) associated to the aerobic training may improve RE and the performance of runners at distances of 3 km(24) and 5 km(12). As the physiological indexes associated with aerobic efficiency ($\dot{V}O_2$max and exercise lactate response) were not modified in these studies, the authors attributed the efficiency improvement to modifications that the plyometric training caused in the RE. The neural adaptation (higher neural activation of the motor units) and the increase on the capacity of using the stored elastic energy in the muscle-tendon set have been pointed as the probable mechanisms to determine an improvement on RE with the plyometric training(13).

In our study, however, no significant correlation of the maximal isotonic strength and VJ with RE was found. It is important to observe that the mechanisms considered as responsible for the improvement on RE with the plyometric training are potentially present in the type of jump evaluated in our study. Thus, it is possible hypothesizing that the variables analyzed in the present study (maximal isotonic strength and VJ) do not fully reflect the modifications imposed by the explosive strength training that lead to improvements on the RE. This hypothesis is corroborated, at least in part, by data recently obtained by Turner *et al.*(25), who verified improvements in RE with plyometric training without, however, finding significant modifications in VJ or in the variables that could indicate improvement in the capacity of storing and using the elastic energy. We must recognize the limitation of our experimental design, which is frequently found in other studies(2,5), of evaluating RE at only one velocity (14 km/h). Some authors have suggested that the inter-individual RE behavior may depend on the velocity analyzed, in other words, more economic athletes at moderate velocities (14-15 km/h) are not necessarily more economic in higher velocities (> 19 km/h)(26). In these more intense velocities, however, the test duration and/or the moment when the $\dot{V}O_2$ values are analyzed may influence the RE calculation in function of the existence of the $\dot{V}O_2$ slow component. In these conditions, the existence of an anaerobic contribution is not disregarded, which is usually ignored or the method used for its determination may present validity problems. Anyway, further studies aimed at identifying the mechanisms responsible for the improvement in the RE after the addition of the plyometric training to the aerobic training seem to be necessary.

CONCLUSION

Based on the results presented in this study, we may conclude that the maximal aerobic power explains in part the inter-individual RE variations in endurance athletes. However, the maximal isotonic strength and the explosive strength seem not to be associated with the RE values in this group of athletes.

All the authors declared there is not any potential conflict of interests regarding this article.

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