

Research article

Relationship between training status and maximal fat oxidation rate

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Abstract

This study aimed to compare maximal fat oxidation rate parameters between moderate- and low-performance runners. Eighteen runners performed an incremental treadmill test to estimate individual maximal fat oxidation rate (Fat_{max}) based on gases measures and a 10,000-m run on a track. The subjects were then divided into a low and moderate performance group using two different criteria: 10,000-m time and VO_{2max} values. When groups were divided using 10,000-m time, there was no significant difference in Fat_{max} (0.41 ± 0.16 and 0.27 ± 0.12 g.min⁻¹, $p = 0.07$) or in the exercise intensity that elicited Fat_{max} (59.9 ± 16.5 and 68.7 ± 10.3 % $\dot{V}O_{2max}$, $p = 0.23$) between the moderate and low performance groups, respectively ($p > 0.05$). When groups were divided using VO_{2max} values, Fat_{max} was significantly lower in the low VO_{2max} group than in the high VO_{2max} group (0.29 ± 0.10 and 0.47 ± 0.17 g.min⁻¹, respectively, $p < 0.05$) but the intensity that elicited Fat_{max} did not differ between groups (64.4 ± 14.9 and 61.6 ± 15.4 % $\dot{V}O_{2max}$). Fat_{max} or % $\dot{V}O_{2max}$ that elicited Fat_{max} was not associated with 10,000 m time. The only variable associated with 10,000-m running performance was % $\dot{V}O_{2max}$ used during the run ($p < 0.01$). In conclusion, the criteria used for the division of groups according to training status might influence the identification of differences in Fat_{max} or in the intensity that elicits Fat_{max} .

Key words: fat oxidation; running performance; indirect calorimetry.

Introduction

Fat and carbohydrate (CHO) are the main substrates for energy production during exercise. It has been well characterized that absolute carbohydrate oxidation increases linearly as the exercise intensity increases, while fat oxidation increases progressively from rest to approximately 60% of maximal oxygen uptake (VO_{2max}) and then decreases gradually until it reaches the VO_{2max} (Achten and Jeukendrup, 2004; van Loon et al., 2001; Venables et al., 2005). Achten et al. (2002) examined the fat oxidation over a wide range of exercise intensities and found a maximal level of fat oxidation rate (Fat_{max}) to be around 63% of VO_{2max} , suggesting the existence of an optimal intensity for the fat oxidation.

Endurance training provides several metabolic adaptations in exercising muscle related to the capacity to oxidize fat during exercise (Friedlander et al., 2007). However, the magnitude at which the aerobic training status could influence the Fat_{max} has not been fully estab-

lished. For example, Nordby et al. (2006) found that trained subjects had a higher Fat_{max} that occurred at a higher intensity than in untrained subjects, whilst Stisen et al. (2006) did not find any differences between trained and untrained women in analyzing this same parameter.

These contradictory results might be explained by the criteria used for determination of the aerobic training status. In these studies (Nordby et al., 2006; Stisen et al., 2006), subjects with high and low VO_{2max} values were compared, assuming that the higher VO_{2max} values represented the more trained subjects. However, even if the VO_{2max} is used frequently as a physiological parameter to discriminate the aerobic fitness (Costill et al., 1973; Wyndham et al., 1969), there are some studies that have indicated it may have limited power in predicting the endurance performance (Morgan et al., 1989; Noakes et al., 1990). This limited predictive power could be due to a complex interplay between other physiological factors beyond the VO_{2max} and the endurance performance (Weston et al. 1999). Therefore, the relationship between Fat_{max} and performance needs to be fully explored.

It is likely that the criteria for determination of the aerobic training status can influence the magnitude of differences on the Fat_{max} . As a result, we hypothesized that the Fat_{max} parameters should be greater for the best runners and that the sharper differences on the Fat_{max} parameters are dependent on the criteria used to determine the training status. Thus, the objective of the present study was to analyze the impact of training status on the Fat_{max} and exercise intensity that elicits the Fat_{max} , employing performance as different comprehensive criteria for categorizing the subjects.

Methods

Subjects

Eighteen athletes took part in this study, which was approved by an Institutional Review Board for use of human subjects. Each volunteer gave a written informed consent after experimental procedures, possible risks and benefits had been explained. All subjects were amateur competitors in regional or national 10,000 races in track and field championships, with a training background between 3 and 10 years. The subjects were included only if they had performed at least ten 10-km running races in the two years before the study and if they trained continuously for the last three years. The characteristics of the subjects are shown in Table 1.

Table 1. Physical and physiological characteristics of the subjects. Data are means (\pm SD).

Age (years)	28.0 (4.9)
Height (m)	1.71 (0.07)
Body weight (kg)	65.7 (9.9)
VO ₂ max (ml·kg ⁻¹ ·min ⁻¹)	62.4 (6.9)
10-km running race numbers-last two years	12.0 (1.0)

VO₂max: maximal oxygen uptake.

Incremental test

In the first visit, anthropometric variables were measured, followed by a treadmill incremental test for individual estimation of fat oxidation rates over a range of speeds. The test started with 6 km·h⁻¹ and was increased by 1.2 km·h⁻¹ at 3-min intervals until exhaustion (Heck et al., 1985). According to Achten et al. (2002), 3-min increases provide similar Fat_{max} results when compared to a continuous prolonged protocol. Therefore, this protocol with shorter stage duration (3-min) was chosen for practical reasons. Respiratory gases were analyzed and recorded breath by breath continuously throughout the test using an online integrated indirect calorimetry system (K4b², Cosmed, Italy) calibrated prior to each test according to manufacturer specifications. VO₂max was calculated as the greatest mean VO₂ value obtained over the last 30 s of the test.

Determination of fat oxidation rate

Means of VO₂ and VCO₂ were calculated over the last 45 s for every stage of the incremental test. The fat oxidation rate was calculated using the following stoichiometric equation (Frayn, 1983), assuming that the urinary nitrogen excretion rate was negligible:

$$\text{Fat oxidation} = 1.67 \text{ VO}_2 - 1.67 \text{ VCO}_2$$

where VO₂ and VCO₂ are reported as l·min⁻¹ and oxidation rate as g·min⁻¹.

The fat oxidation rate was plotted as a function of exercise intensity, expressed as percentage of VO₂max. The following variables were identified on individual fat oxidation curves: Fat_{max} (highest fat oxidation rate expressed as g·min⁻¹); %VO₂max that elicited Fat_{max} (%VO₂max at which the highest fat oxidation was observed); and, VO₂ and respiratory exchange ratio (RER) at the Fat_{max}. The intensity of the Fat_{max} was also expressed as speed (km·h⁻¹) and percentage of maximal heart rate (%HR_{max}).

10,000-m running performance

Approximately 14 days after the incremental test, all subjects performed a 10,000-m run on a 400-m track. The subjects were instructed to complete the run as quickly as possible, as they would in a competitive event. Verbal encouragement was used to achieve the fastest possible times. The time per 400 m was recorded and the average speed and the percentage of VO₂max (%VO₂max) used during the run were calculated.

Group sharing

Analysis of whole group (pooled data) showed an average

time to cover the 10,000 m of 37.8 min. The subjects were split in two groups according to their 10,000-m time. Times above 37.8 min were classified as low performance and times below 37.8 min as moderate performance. The term “moderate performance” was chosen instead of “high performance” as previous studies have shown that elite runners are able to run 10,000 m within a range of 28 to 33 min (Coetzer et al., 1993; Weston et al., 1999). Additionally, the subjects had similar 10-km race experience before the study. There was no difference between the moderate and low performance groups (12 \pm 1 vs 11 \pm 1) in the number of 10-km running races performed in the last two years before the study.

The VO₂max average for the whole group (pooled data) was 62.4 ml·kg⁻¹·min⁻¹. The subjects were also split in a group with VO₂max below (low VO₂max group) and above 62.4 ml·kg⁻¹·min⁻¹ (high VO₂max group). The use of average of VO₂max values as a criterion for group allocation has been previously described (Achten and Jeukendrup, 2003).

Statistical analysis

Values are expressed as mean and standard deviation. An unpaired t-test was used to compare the variables between low and moderate performance groups or between high and low VO₂max groups. Pearson's correlation coefficient was calculated to determine possible associations between 10,000-m performance and substrate oxidation parameters. A level of significance of 5% (p < 0.05) was adopted in all analyses.

Results

Whole group

The Fat_{max} average was 0.36 \pm 0.15 g·min⁻¹ and was observed at an exercise intensity of 9.7 \pm 2.3 km·h⁻¹, corresponding to 63.3 \pm 14.7 %VO₂max or 71.1 \pm 12.1 %HR_{max}. The 10,000 m run was completed with a mean speed of 16.0 \pm 1.4 km·h⁻¹, corresponding to 94.5 \pm 5.1 %VO₂max.

Differences between low and moderate performance groups

The time to complete the 10,000 m was significantly different (p < 0.0001) between groups, 41.3 \pm 2.2 min for the low performance group (n = 7) and 35.5 \pm 1.7 min for the moderate performance group (n = 11) (Table 2). VO₂max did not differ between moderate and low performance groups (Table 2). There were no differences in age, body weight, height or HR_{max} between groups. No difference in the Fat_{max} values was observed between moderate and low performance groups, although this parameter tended toward higher values (p = 0.06) in moderate performance group (Table 2). The VO₂ at the Fat_{max} was not significantly different between groups, but RER at the Fat_{max} was higher in the moderate than in the low performance group. The intensity that elicited Fat_{max} did not differ between groups and was located around 59.9 \pm 16.5 and 68.7 \pm 10.3 %VO₂max in moderate and low performance groups, respectively (Table 2). The moderate performance group covered the 10,000 m with a higher %VO₂max (p < 0.01) than the low performance group

Table 2. Physiological parameters, fat metabolism parameters and 10,000-m running performance in the low and moderate performance groups. Data are means (\pm SD).

	Low performance (n =7)	Moderate performance (n = 11)
VO ₂ max (ml·kg ⁻¹ ·min ⁻¹)	59.4 (5.9)	64.3 (7.1)
Time to cover 10,000 m (min)	41.3 (2.2)	35.5 (1.7) *
Average speed during 10,000 m (km·h ⁻¹)	14.5 (.7)	16.9 (.8) *
%VO ₂ max at 10,000 m	89.9 (4.6)	97.4 (2.8) *
Fat _{max} (g·min ⁻¹)	.27 (.12)	.41 (.16)
VO ₂ at Fat _{max}	38.2 \pm 9.4	41.0 (8.9)
RER at Fat _{max}	.89 (.05)	.94 (.03) *
% VO ₂ max at Fat _{max}	68.7 (10.3)	59.9 (16.5)
Speed at Fat _{max} (km·h ⁻¹)	10.5 (1.9)	9.2 (2.4)

%VO₂max at 10,000 m: percentage of maximal oxygen uptake during a 10,000-m race; Fat_{max}: maximal fat oxidation rate; VO₂ at Fat_{max}: oxygen uptake at intensity correspondent at Fat_{max}; RER at Fat_{max}: respiratory exchange ratio at intensity correspondent at Fat_{max}; %VO₂max at Fat_{max}: percentage of maximal oxygen uptake that elicited Fat_{max}; speed at Fat_{max}: running speed that elicited Fat_{max}. * Significant difference between groups (p < 0.01).

(Table 2). There was no observed correlation between Fat_{max}, %VO₂max or speed elicited from the Fat_{max} measures and the 10,000-m times (Table 3). However, the fraction of VO₂max used during the run was significantly associated with 10,000-m time (p < 0.01).

Table 3. Correlation coefficients between physiological or fat metabolism parameters and 10,000-m running performance.

	Time to cover 10,000 m
%VO ₂ max at 10,000 m	-.74 **
Fat _{max} (g·min ⁻¹)	-.23
%VO ₂ max at Fat _{max}	.42
Speed at Fat _{max} (km·h ⁻¹)	.33

%VO₂max at 10,000 m: percentage of maximal oxygen uptake during a 10,000-m race; Fat_{max}: maximal fat oxidation rate; %VO₂max at Fat_{max}: percentage of maximal oxygen uptake that elicited Fat_{max}; speed at Fat_{max}: running speed that elicited Fat_{max}; ** p < 0.01.

Differences between low and high VO₂max groups

VO₂max was 58.6 \pm 5.4 ml·kg⁻¹·min⁻¹ in the low VO₂max group (n = 11) and 68.4 \pm 4.5 ml·kg⁻¹·min⁻¹ in the high VO₂max group (n = 7) (p < 0.05). No differences in age, body weight, height or HR_{max} were observed between groups. The Fat_{max} was significantly lower in the low VO₂max group than in the high VO₂max group (Table 4; p < 0.05). Nevertheless, VO₂ and RER at the Fat_{max} were not significantly different between groups. The intensity that elicited the Fat_{max} did not differ between groups and was located around 64.4 \pm 14.9 and 61.6 \pm 15.4 % VO₂max in the low and high VO₂max groups, respectively (p > 0.05). There was also no difference in 10,000-

m running performance between groups [low VO₂max: 38.7 \pm 3.5 min, high VO₂max: 36.4 \pm 3.1 min, p > 0.05].

Discussion

The main finding of the present study was the lack of difference in the Fat_{max} between the moderate and low performance groups, even though the Fat_{max} tended to be higher in the moderate group. However, when VO₂max was used as a criterion for sharing the groups, the Fat_{max} values were significantly higher in high VO₂max group. Another important finding was the lack of significant association between fat oxidation parameters and 10,000-m running performance.

The Fat_{max} average obtained for both groups (0.36 g·min⁻¹) was slightly lower than that reported in previous studies (Achten et al., 2002; 2003; González-Haro et al., 2007). These studies employed a cycle ergometer protocol, whereas, a treadmill incremental protocol was employed in the present investigation. To our knowledge, only one study compared the Fat_{max} during treadmill exercise with cycle ergometer exercise (Achten et al., 2003). The fat oxidation rate was significantly higher during treadmill exercise compared to cycling exercise over a wide intensity range. Unfortunately, the subjects in Achten's et al. study (2003) performed an uphill walk instead of treadmill running, which could exclude comparisons with the results from our study. Nevertheless, it could be speculated that the energy expenditure is higher during running compared to walking or cycling, resulting in a greater contribution of carbohydrate oxidation and a

Table 4. Physiological parameters, fat metabolism parameters and 10,000-m running performance in the low and high VO₂max groups. Data are means (\pm SD).

	Low VO ₂ max (n =11)	High VO ₂ max (n =7)
VO ₂ max (ml·kg ⁻¹ ·min ⁻¹)	58.6 (5.4)	68.4 (4.5) *
Time to cover 10,000 m (min)	38.7 (3.5)	36.4 (3.1)
Average speed during 10,000 m (km·h ⁻¹)	15.6 (1.4)	16.6 (1.3)
%VO ₂ max at 10,000 m	93.7 (6.0)	95.9 (3.3)
Fat _{max} (g·min ⁻¹)	.29 (.10)	.47 (.17) *
VO ₂ at Fat _{max}	37.7 (8.8)	41.9 (9.5)
RER at Fat _{max}	.93 (.03)	.89 (.07)
% VO ₂ max at Fat _{max}	64.4 (14.9)	61.6 (15.4)
Speed at Fat _{max} (km·h ⁻¹)	9.6 (2.1)	9.8 (2.6)

%VO₂max at 10,000 m: percentage of maximal oxygen uptake during a 10,000-m race; Fat_{max}: maximal fat oxidation rate; VO₂ at Fat_{max}: oxygen uptake at intensity correspondent at Fat_{max}; RER at Fat_{max}: respiratory exchange ratio at intensity correspondent at Fat_{max}; %VO₂max at Fat_{max}: percentage of maximal oxygen uptake that elicited Fat_{max}; speed at Fat_{max}: running speed that elicited Fat_{max}. * Significant difference between groups (p < 0.05).

lower fat oxidation. In the present study RER values at the Fat_{max} exceeded 0.85 units in all subjects, suggesting that carbohydrate oxidation was the major fuel at Fat_{max} intensity. When analyzed by groups, RER values showed a higher carbohydrate oxidation in the Fat_{max} intensity in moderate performance group.

A higher fat oxidation rate during submaximal exercise in trained individuals has been observed (Nordby et al., 2006; Stisen et al., 2006). However, the training effects on the Fat_{max} and intensity that elicits the Fat_{max} is not evident (Achten and Jeukendrup, 2003; Nordby et al., 2006; Stisen et al., 2006). For instance, Nordby et al. (2006) found that the Fat_{max} occurred at higher relative workloads in trained subjects compared with untrained subjects, while Stisen et al. (2006) observed no differences in the Fat_{max} or intensity that elicits the Fat_{max} between trained and untrained women. Achten and Jeukendrup (2003) also found no differences in the Fat_{max} intensity between individuals with high or low VO_{2max} . In the present study, we found a higher Fat_{max} in high VO_{2max} group when VO_{2max} was used to determine the aerobic training status. However, the intensity that elicited the Fat_{max} was not different between groups. On the other hand, we observed no difference in the Fat_{max} or Fat_{max} intensity between moderate and low performance groups. It is worthy of note that there was a larger intra-individual variation in intensity that elicited Fat_{max} , as demonstrated by elevated standard deviation for both the groups. Nevertheless, the criterion used to determine the aerobic training status can affect the magnitude of differences on the Fat_{max} . Consequently, performance parameters should be cautiously employed when the training effects on the Fat_{max} are studied through data from transversal investigations.

It should be noted that athletes selected for the present study cannot be considered as elite runners (Coetzer et al., 1993; Weston et al., 1999). In fact, Coetzer et al. (1993) and Weston et al. (1999) suggested that elite runners are able to run 10,000 m below 33 min. The faster group in the present study covered 10,000-m in 35.5 ± 1.7 min. Therefore, we preferred to use the term "moderate performance" instead of "high performance" in order to characterize the faster group. However, the differences between the moderate and low performance groups, with regard to the time to cover 10,000-m, was about 6 min ($p = 0.00001$). This suggests that even though the moderate group was classified as better runners and had a better performance level than their counterparts in the low performance group they did not have a difference in Fat_{max} . The higher proportion of VO_{2max} used during the run, not the fat oxidation parameters, was associated with 10,000-m running performance. These results could suggest that the performance during a 10,000-m run might depend on capacity to oxidize carbohydrates rapidly, since higher exercise intensities requires energy derived from carbohydrate fuel (Brooks and Mercier, 1994; Brooks and Trimmer, 1996). Previously, Bergman and Brooks (1999) demonstrated that trained subjects were able to maintain a greater workload and energy expenditure at intensities around 59 and 75% VO_{2max} and this greater mechanical power output was covered by an in-

creased carbohydrate oxidation rate. Friedlander et al. (2007) showed that carbohydrates are the main fuel used by working muscle during exercise in moderate and high intensities, although endurance training increases the oxidation capacity for all substrates. However, as we did not measure carbohydrate oxidation during the run, this assumption remains unclear and questions arising from this require further investigation. Nevertheless, if athletes used more energy at an equal fat oxidation, it could suggest a greater carbohydrate oxidation.

Conclusion

In conclusion, the results show that the criteria used for categorizing aerobic training status of the subjects can influence the magnitude of differences in the Fat_{max} or exercise intensity that elicits the Fat_{max} . When the performance during a simulated event was used to determine performance status, we did not find significant training effects on the Fat_{max} or intensity that elicits the Fat_{max} . In addition, it is possible that 10,000-m running performance is associated with an increased ability for carbohydrate oxidation. However, further studies that address this question are necessary.

Acknowledgments

We are grateful to Edson Degaki for the technical assistance. Flávio Pires is grateful to CAPES for his PhD scholarship.

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Key points

- The results of the present study suggest that the criteria used to categorize aerobic training status of subjects can influence the magnitude of differences in Fat_{max} .
- The Fat_{max} is similar between groups with similar 10,000-m running performance.
- The 10,000-m running performance seems to be associated with an increased ability to oxidize carbohydrate.

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