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DETERMINATION OF ACCUMULATED OXYGEN DEFICIT DURING A 400M RUN

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ABSTRACT

DETERMINATION OF ACCUMULATED OXYGEN DEFICIT DURING A 400M RUN. **Reis VM, Duarte JA, Espirito-Santo J, Russell AP**. **JEP**online. 2004;7(2):77-83. We studied ten male athletes performing a 400 m all-out track run in order to measure the accumulated O_2 deficit (AOD), the energy cost of running (C_r) and the percentage anaerobic contribution to total energy release (E_{AN}). Prior to the 400 m run, subjects underwent several five min constant intensity running bouts between 50% and 100% VO_2max to establish the individual VO_2-speed relationship. Oxygen uptake was measured with a portable analyser (Cortex Metamax I). During the 400 m all-out track run estimated AOD, C_r and E_{AN} were 60.75 ± 6.25 mL O_2 Eq/kg, 0.200 ± 0.014 mL O_2 Eq/kg/m and 75.9 ± 5.5%. The mean 400 m speed was 7.43 ± 0.32 m/s. Oxygen uptake during the 400 m run reached ~52% of subjects' peak VO_2. Unlike many laboratory measures of the AOD, the field-based estimations of the AOD in the present study did not correlate with 400 m speed. The main findings of this study were that during high-intensity track running for less than 1 min, the AOD and E_{AN} are relatively high while the VO_2 is low. These results highlight the need for testing the respiratory response during high-intensity running in field, rather than under laboratory conditions, particularly when testing sprint runners.

Keywords : Anaerobic capacity, Athletics, Sprinting

INTRODUCTION

Since the late 1980´s there has been an increased focus on the concept and methodology of the accumulated O_2 deficit (AOD) as an indicator of the anaerobic capacity. In a series of laboratorial investigations, Medbo et al. (13) re-examined the AOD and suggested it to be a valid method to quantify anaerobic energy release. Despite the criticisms that have been addressed to the method (1), several investigators have used the AOD to study the respiratory response of 400 m runners during high-intensity treadmill running (5,6,22).
Since the AOD is considered an acceptable non-invasive measure of anaerobic capacity (13), numerous investigations have attempted to relate this parameter to 400 m running performance and have observed significant correlation coefficients ranging from 0.44 to 0.82 (5,18,24). These discrepancies between results may reflect limitations with the method when comparing laboratory to field conditions. Indeed, the majority of laboratory studies were conducted using a steep treadmill gradient (13,16). It has been demonstrated that the inclination of the treadmill produces a higher energy cost and considerable alterations in the estimated

AOD (16,21). Therefore, it is not known if the AOD kinetics under supra-maximal track running is similar to the AOD kinetics that is observed on the treadmill. While there are some reports of metabolite-based AOD estimations during high intensity track running (11), we have not found any published reference to respiratory-based AOD estimations. This lack of data seems unjustified since, with the validation of portable oxygen analysers, it is now possible to accurately assess the respiratory responses and the metabolic requirements under field conditions.

Therefore, the main aim of this study was to estimate the AOD during 400 m track running as well as to investigate the relationship between the AOD and performance in well-trained 400 m runners. Moreover, the present work also intended to estimate the energy cost of running (C_r) and the percentage anaerobic contribution to total energy release (E_{AN}) during a 400 m all-out track run.

METHODS

Subjects

Ten male 400 m runners gave informed consent to participate in this study. All the subjects underwent a complete medical examination prior to the experiments. The subjects mean (± standard deviations) age, height, body mass, peak oxygen uptake and personal best 400 m performance time were 21.1 ± 4.0 years, 1.80 ± 0.07 m, 69.10 ± 5.48 kg, 62.9 ± 4.4 mL/kg/min and 49.58 ± 3.48 s, respectively. The procedures were in accordance with the Helsinki Declaration of 1975. The subjects performed a sub-maximal track running test, followed 48 hours later by a supra-maximal test (400 m all-out track run). As the study was performed in the final week of the subjects' off-season, and no training was performed by the subjects during the testing period.

Procedures

Sub-maximal test

Subjects performed a m/s with a further 0.56 m/s increase at each subsequent step. Oxygen uptake (VO_2) was measured breath-by-breath and then averaged as 10 s intervals, using a Cortex Metamax I (Cortex Biophysik, Leipzig, Germany); a portable device previously validated against Douglas Bag techniques (12). Before each test, a reference air calibration of the device was performed using a gas sample with a 16% O_2 concentration and a 5% CO_2 concentration. The steady-state VO_2 for each exercise bout was calculated by averaging the O_2 uptake over the last min of the bout. During this test, the running speed of the subjects was kept constant by a cyclist using an electromagnetic speedometer bicycle and the subjects were instructed to follow him at a safe distance, between 1 and 1.5 m. No warm-up was performed before the start of the test and recovery between successive bouts was individualized. The subjects started each bout when their O_2 uptake dropped to a value within 3 mL/kg/min from that recorded before the start of the preceding bout. The test was stopped when voluntary exhaustion occurred. The highest VO_2 record was taken as the subject's peak VO_2.

Supra-maximal test (400 m run)

The supra-maximal test consisted of an all-out 400 m track run. Subjects were allowed to perform their regular warm-up procedures and were asked to run as if they were in a timed competition race. However, the test was not started until the subjects' VO_2 returned to resting values (the same individual value recorded for each subject before the start of the sub-maximal test). Each runner performed the test individually. Although running speed varied throughout the 400 m run, the mean running speed measured during the test was used for all calculations. Ear lobe capillary blood sample collections were made 3 min post race and every 2 min until blood lactate concentration ([La]) levelled off. Whole blood lactate concentration was measured using an Accusport Lactate Analyser (Boehringer, Mannheim, Germany). Before each testing, a calibration of this device was performed, using YSI 1530 Standard Lactate Solutions (2.5, 5, 10 and 15 mmol/L). Oxygen uptake was also measured breath-by-breath during this test with the Cortex Metamax I and then averaged as 10 s intervals. The aforementioned calibration procedure was also performed before each test.

Calculations Of Energy Cost Of Running, Accumulated Oxygen Deficit And Anaerobic Fraction Of Energy Release

The energy cost of running (C_r) in the sub-maximal test was determined from the slope of the VO_2-speed regression line. Since the subjects performed the test with a portable oxygen analyser that weighed 2.3 kg, C_r was corrected for total load (body mass plus 2.3 kg). Therefore, all regression-dependent estimations also included this correction. The VO_2-speed regressions were developed using the steady-state VO_2 values and the corresponding speeds, as well as an individual resting VO_2 measurement (zero speed VO_2). When the last bout of the sub-maximal tests lasted less than 5 min, the VO_2 value was not included in the regression equation. The linear regression equation calculated for each subject was used to extrapolate to the estimated accumulated O_2 demand (AO^{Demand}). As the accumulated O_2 uptake (AO^{uptake}) was measured during the 400 m race, the AOD was calculated as the difference between the AO^{Demand} and the AO^{uptake}. This estimation was not corrected for the body's oxygen stores. Energy cost of running during the supra-maximal test was calculated by dividing the AO^{Demand} by the distance covered. The anaerobic fraction of the energy released (E_{AN}) was obtained by dividing the AOD by AO^{Demand}. The error for AOD estimation was determined by the following formula:

$$\text{AOD error} = \sqrt{(AO^{Demand}\ \text{error}^2 + AO^{uptake}\ \text{error}^2)} \qquad (\textit{Equation 1})$$

where,

$$AO^{Demand}\ \text{error} = O_2\ \text{demand error x duration of the test} \qquad (\textit{Equation 2})$$

and,

$$AO^{uptake}\ \text{error} = O_2\ \text{uptake error x duration of the test} \qquad (\textit{Equation 3})$$

The O_2 demand error was taken as the standard error of the predicted O_2 demand and the error for O_2 uptake measurement was taken as 3%, as suggested by Robergs and Burnett (19).

Statistical analysis

Data analysis and graphics respectively, were performed using SPSS 11.0 and SigmaPlot 8.0 (SPSS Science, Chicago, USA). Simple linear regressions were used on all appropriate data and correlations were determined by the Pearson Product Moment Correlation Coefficient. The correlation coefficient and the standard error of the regression were used as indicators of the fitness of the regression lines. The standard error of the predicted value was used as an indicator of the validity of the linear extrapolation of the energy cost of running. In all statistical analyses the level of significance was set at $p \leq 0.05$. Data are presented as individual values or as means ± standard deviations.

RESULTS

The VO_2-speed regressions presented an acceptable fit, as mean R-values were 0.998 ± 0.002 with a mean standard error of the regression of 1.61 ± 0.60 mL/kg/min. The VO_2 steady state was attained for all subjects in less than 5 min during the exercise intensities below 90% peak VO_2. During higher exercise intensities, the steady state was not observed for some of the subjects. Figure 1 represents the regression line obtained from the sample's mean VO_2-speed values. Sub-maximal energy cost of running averaged 0.190 ± 0.014 mL O_2 Eq/kg/m, after correction for the carried backpack load.

Mean Energy cost of running (C_r) during the 400 m run was 0.200 ± 0.014 ml O_2 Eq/kg/m, the accumulated O_2 deficit (AOD) was 60.75 ± 6.25 ml O_2 Eq/kg and the anaerobic energy fraction (E_{AN}) was $75.9 \pm 5.5\%$. Table 1 presents subjects' values for these variables, as well as for race time (T_{400}), mean speed time (V_{400}) and peak blood lactate concentration ([La]).

Table 1. Individual and mean data for measurements and estimations of variables during the supra-maximal test.

subject	***AOD***	C_r	E_{AN}	T_{400}	V_{400}	***[La]***
	ml O_2 Eq/kg	ml O_2 Eq/kg/m	%	s	M/s	mmol/L

PR	57.76	0.179	80.7	53.5	7.48	13.6
CS	71.20	0.222	80.2	54.1	7.34	13.3
DP	61.37	0.201	76.3	50.8	7.89	16.3
EM	54.24	0.182	74.5	52.0	7.69	13.5
LC	70.27	0.212	82.9	53.6	7.46	13.7
WO	55.93	0.208	67.2	52.5	7.62	13.1
S0	57.37	0.188	76.3	52.1	7.68	15.0
MG	62.79	0.197	79.7	56.4	7.09	12.5
GR	53.34	0.200	66.7	58.5	6.84	12.4
AL	63.26	0.213	74.3	55.6	7.19	11.2
Mean ± SD	60.75 ± 6.25	0.200 ± 0.014	75.9 ± 5.5	53.91 ± 2.33	7.43 ± 0.32	13.46 ± 1.41

Table 2. Pearson product moment correlation coefficients between variables.

	AOD	C_r	E_{AN}	***[La]***
V_{400}	-0.05	-0.26	0.19	0.78**
[La]	-0.02	-0.28	0.24	
E_{AN}	0.71*	0.01		
C_r	0.70*			

Abbreviations: AOD = accumulated O_2 deficit, C_r = energy cost of running, E_{AN} = anaerobic energy fraction, [La] = blood lactate concentration, V_{400} = mean speed. * $P \leq 0.05$; ** $P \leq 0.01$.

Significant correlations were found between V_{400} and [La], between AOD and C_r, and between AOD and E_{AN}. The relationships between variables are presented in Table 2. Correlations including T_{400} are not presented, as they are implied in the V_{400} correlations. Figure 2 illustrates the oxygen uptake kinetics and oxygen deficit during the 400 m run.

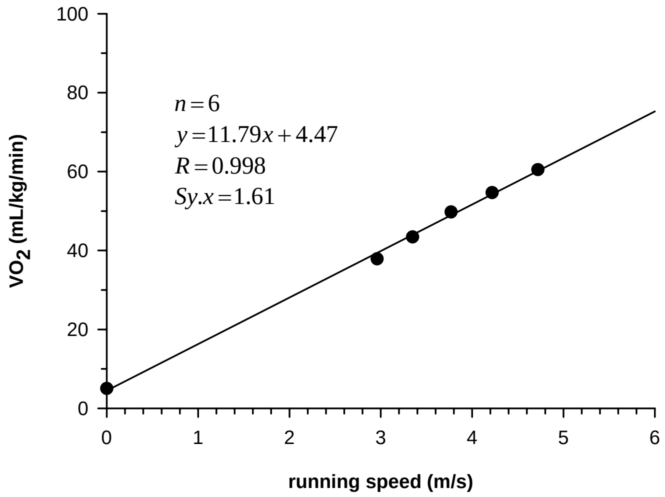

Figure 1. Regression line obtained from mean VO_2-speed values for the subjects. *Abbreviations*: *n* = number of points in the regression, *R* = correlation coefficient, *Sy.x* = standard error of the regression. The regression line equation is also indicated.

DISCUSSION

In the present study, the AOD estimated during the 400 m all-out field running performance was 60.75 ± 6.25 ml O_2 Eq/kg. This value is more than 10% higher than the mean values observed for sprint and middle-distance runners when performing constant-intensity horizontal treadmill running (17,22,24). The 400 m performance level of the subjects in the present study and of those in the aforementioned studies were similar. Therefore, it appears that an all-out field running protocol results in a higher AOD value than a constant-intensity treadmill protocol. However, the AOD values estimated in the present study are lower than those performed on a treadmill with a 10.5% inclination (13,16). Indeed, it has been shown that the AOD increases with the treadmill inclination (13,16,21) and this could explain the differences in the AOD values between the studies. It has been demonstrated (13) that the maximal AOD during running occurs with exercise durations above 2 min and that during 1 min of exhaustive running, only about 75% of the maximal AOD is attained. However, in laboratory treadmill investigations, supra-maximal tests are performed using constant speeds, unlike the all-out effort used in the present study. It has been reported during cycling (4) that the AOD kinetics is faster

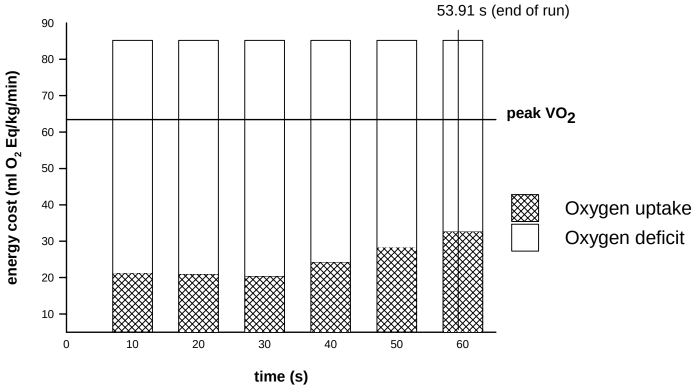

Figure 2. Mean oxygen uptake and mean oxygen deficit during the 400m run.

when supra-maximal tests are conducted under all-out conditions. Therefore, it is possible that during all-out track running the AOD rises much faster and attains maximal values sooner than during a 2 min constant-intensity running test. Additionally, the maximal AOD during all-out track running may be considerably higher than horizontal treadmill laboratory estimations. The error for the AOD estimation in the present study was 1.87 ± 0.90 ml O_2 Eq/kg, representing ~3.1% of the subjects' mean estimated AOD, a lower value than the 4% observed by Medbo et al. (13) when they validated the method for laboratory treadmill running. Therefore, the validity of the method for high-intensity track running seems acceptable.

It has been suggested that the AOD estimated under laboratory conditions could be a good predictor of 400 m running performance (24). This has been supported by significant correlations shown between laboratory AOD estimations and 400 m race performance (5, 18). However our results do not support these observations as, like others (17), we failed to observe a correlation between the AOD calculated during a 400 m all-out exhaustive test and the performance time. These discrepancies underline the potential problems when trying to predict performance from laboratory tests and highlight the need for more specific field-testing, as performed in the present study. The low correlation may also be due to the fact that these are a fairly homogeneous group of runners or that additional factors to AOD influence 400 m track run performance.

As the supra-maximal test was an all-out effort, the running speed, and therefore the C_r were not constant. Therefore, the C_r was also not constant. However, for all calculations the running speed and C_r were averaged. As both AOD and E_{AN} estimations are amounts and not rates, their estimations will not be influenced by the C_r averaging procedure. Our subjects' performances in the 400 m run (53.91±2.33 s) were well below their best performances (49.58 ± 3.48 s). This discrepancy may result from the following facts: the testing was applied in the off-season, the subjects carried a 2.3 kg backpack load and the subjects ran individually, without direct competition.

Our values for C_r (0.200±0.014 ml O_2 Eq/kg/min) are different from the 400 m track running estimation of 0.274 ml O_2 Eq/kg/min by Lacour et al. (11), but close to that reported by Hill (7), 0.205 ml O_2 Eq/kg/min O_2. Both of these authors estimated the anaerobic energy from blood lactate measurements. However, anaerobic energy estimation from blood lactate is a questionable procedure, as blood lactate concentration cannot accurately reflect muscle lactate production (14). Additionally, the fact that the subjects in the study by Lacour et al. (11) presented a better 400 m performance level (~45.5 s) than the subjects in the present study and that the data was collected during competition races, may be also responsible for the differences.

Using respiratory-based estimations, we found the anaerobic contribution to total energy release (E_{AN}) during a 400 m race to be 75.9 ± 5.5%. Estimations of the E_{AN} during 50 s to 1 min of high intensity constant speed treadmill running (22, 23) were lower than the mean values we have found. These comparisons between studies suggest that the E_{AN} is higher during an all-out, as compared to a constant speed laboratory test. One might speculate that the extremely high energy demand during the initial phase of an all-out test (e.g. the first 20 to 30 s), may cause a metabolic response that delays the VO_2 response. Indeed, the subjects' mean VO_2 at the end of the run in the present study attained no more than 32.69±10.03 $ml.kg^{-1}.min^{-1}$, representing ~52% of their peak VO_2 (see Fig. 1). Nevertheless, in the first 60 s after the run, the VO_2 attained a mean value representing ~85% of peak VO_2. The ventilation presented concomitantly low values during the run (~35 L/min^1 during the first 30 s, with breathing frequencies below 30 per minute), but demonstrated high values during the recovery (from 100 to 140 $L.min^{-1}$). Although the Cortex Metamax I device has a built-in-averaging in the data handling that can delay the reported VO_2 compared with the true value (12), the unexpected low VO_2 values cannot solely be explained by this phenomenon. Interestingly it has been suggested that VO_2 kinetics is slower in fast-twitch than in slow-twitch muscle fibres (10). If a high percentage of fast-twitch (and concomitantly a low percentage of slow-twitch) fibres were recruited during the run, especially in the first half of the run, it seems possible that the VO_2 response could be considerably delayed. When sprinters run at their maximal speed, electromyography (EMG) records show that the thigh-muscles' (hamstrings, *vastus medialis* and *gluteus maximus*) coding rate of the motor units are between 120 to 140% of maximal voluntary contraction (MVC), with a value ~200% for the *aductor magnus* (25). Considering that during the first half of a 400 m event, sprinters run at 93-95% of their maximal running speed, it is quite plausible that the muscles' response is well above the MVC. Such elevated EMG records during sprinting seem compatible with large fast-twitch fibre recruitment and a concomitant decreased blood flow (8). In addition, the high stride frequency can also lower the muscle blood flux (9) due to short durations of relaxation between contractions (3). Therefore, these factors could have resulted in a lower O_2 deliver to exercising muscles, explaining the extremely low VO_2 we observed. This hypothetical influence of preferential fast-twitch fibre recruitment on the VO_2 kinetics, could even occur in the last phase of the run, when fatigue mechanisms are more prominent. Bosco et al. (2) demonstrated that, under acid pH conditions, fast-type muscles could reuse greater amounts of stored energy than slow-type muscles, during stretch-shortening cycle exercises, such as sprint running.

Using metabolite-based estimations Lacour et al. (11) calculated the E_{AN} in 400 m competitions to be 72%, a value that is close to the one observed in the present study. In contrast, the metabolite-based estimation of the E_{AN} during 400 m running by Hill (7) was lower at 63%. The lower value described by Hill (7) may be explained by a lower performance level of the athletes tested, when compared to the elite athletes performing in the study by Lacour et al. (11).

The peak blood lactate values measured in the present study are lower than those previously reported when testing 400 m runners during track (11) or inclined treadmill running (15, 20), but higher than other reports for 400 m runners tested during horizontal (24) or inclined treadmill running (5). However, in support of a previous study (11), we also observed a positive correlation between [La] and V_{400} ($r=0.78$, $P \leq 0.01$). Therefore, the differences in [La] between the present study and others may be related to different running speeds. Another possible explanation for these differences may be the phase of the competitive season in which the testing took place. It has been demonstrated that [La] in high intensity running increases during the season, peaking at the most important competitions (11, 15). Our subjects were tested during their off-season.

CONCLUSIONS

The main findings of the present study were that during high intensity track running, for less than 1 min, the AOD and E_{AN} are relatively high, while the VO_2 is low. These results highlight the need for testing the respiratory response during high-intensity running in field, rather than under laboratory conditions, particularly when testing sprint runners.

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