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Changes in the accumulated oxygen deficit and energy cost of running 400 metres

By Victor Machado Reis and Paulo Paixão Miguel

ABSTRACT

The aim of this study was to compare the accumulated oxygen deficit (AOD), the energy cost of running and the anaerobic fraction of energy elicited during all-out 400m track runs in the off-season and summer preparation phases of a season. Five trained 400m runners with an average best time of 47.72 took part in the tests. The authors found that the subjects' performance improved significantly between the two tests but this improvement was not matched by significant changes in the AOD. They did find that the performance improvement was matched by significant decreases in the energy cost of running and oxygen uptake during the run and a significant increase in the anaerobic fraction of energy used. These results suggest that improving high-speed running economy is a key to better performance in the 400m.

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Introduction

Accumulated oxygen deficit (AOD) is considered an acceptable measure of anaerobic capacity (MEDBØ et al., 1988; SALTIN, 1990) and it has been used to analyse the respiratory profile of sprinters during high-intensity treadmill running (HEUGAS and BRISSWALTER, 1995; HEUGAS et al., 1997; OLESEN et al., 1994; SPENCER and GASTIN, 2001; WEYAND et al., 1994). Several investigators have attempted to relate the AOD observed under laboratory conditions to performance in the 400 metres. Subsequent significant correlation coefficients have ranged from 0.44 to 0.82 (HEUGAS and BRISSWALTER, 1995; RAMSBOTTOM et al., 1994; WEYAND et al., 1994) to no association whatsoever (OLESEN et al., 1994; HEUGAS and BRISSWALTER, 2000). However, there are still few references to respiratory-based energy release estimations for sprinting. Using a specific assessment of 400m runners REIS et al. (2004) failed to observe an association between AOD and performance.

The metabolic profile of sprint events has been described by using other indicators, such as the blood lactate concentration or [La] (LACOUR et al., 1990). However, the use of [La] as a quantitative estimation of the anaerobic energy release is questionable due to difficulties such as the unknown amount of lactate transfer from muscles to blood, the unknown degree of lactate dilution in blood and the unknown lactate oxidation in non-active muscles (SALTIN, 1990). FRANCAUX et al. (1993) as well as MEDBØ and TOSKA (2001) have concluded that the [La] does not accurately reflects muscle lactate production.

The validation of automatic portable oxygen analysers (MEDBØ et al., 2000) has brought new horizons into this line of research, allowing respiratory measurements in the field during high-intensity exercising. DUFFIELD and DAWNSON (2003) have assessed respiratory response to estimate the energy system contribution in several sprint events. REIS et al. (2004) also assessed trained subjects during high-intensity track running and have found interesting results. They describe a high AOD when compared with constant-intensity treadmill running (OLESEN et al., 1994; WEYAND et al., 1994; SPENCER and GASTIN, 2001) and an extremely low aerobic demand during races (the oxygen uptake achieved was no more than ~52% of the subjects' peak oxygen uptake). These results support the notion that when sprinters are evaluated in the laboratory their response may not reflect the response during high-intensity track runs.

The effect of high-intensity training on the AOD of non-trained (MEDBØ and BURGERS, 1990; RAMSBOTTOM et al., 2001; WEBER and SCHNEIDER, 2002) and sprint trained (HEUGAS et al., 1997; HEUGAS and BRISSWALTER, 2000) subjects is described in the literature. However, none of the above mentioned studies have assessed sprinters during track running. When the athletes are assessed under laboratory conditions, the measured responses may not reflect the subjects' specific adaptations to the training programme. On the other hand, longitudinal assessment of the AOD of sprinters may be a way to detect the chronic responses of those subjects to a training programme.

The aims of the present study were to compare the AOD, the energy cost of running and the anaerobic fraction of energy elicited during a 400m all-out track run performed by athletes in two phases of a training season (off-season phase and summer preparation phase).

Methods

Subjects

Five national-level 400m runners gave informed consent to participate in the study. The best performance of the subjects was (mean ± standard deviation) 47.72 ± 1.69s. Their mean age, height and mass were 21.4 ± 5.5 years, 1.78 ± 0.08m and 70.0 ± 4.3kg, respectively. The subjects were assessed twice: in the last week of the off-season phase (OSP) and six months later, in the last week of the summer preparation phase (SPP). The procedures were in accordance with the Helsinki Declaration of 1975. In each assessment period, the subjects performed a submaximal running test, followed 48 hours later by a supramaximal test (400m all-out run). On the day between the two tests, subjects performed a low-intensity and low-duration recovery running session.

Submaximal test

The submaximal test included several discontinuous submaximal five minute duration bouts. The test was started at a speed of 2.77m/s^{-1} with a further 0.56m/s^{-1} increase for each subsequent bout. Oxygen uptake (VO_2) was measured breath-by-breath and then averaged at 10-second intervals, using a Cortex Metamax I (Cortex Biophysik, Leipzig, Germany), a previously validated portable device (MEDBØ et al., 2002). 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 flow meter was also calibrated before each testing with a 3000ml syringe. The steady-state VO_2 for each exercise bout was calculated by averaging the O_2 uptake over the last minute 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 of between 1 and 1.5m. No warm-up was performed before the start of the test and recovery between successive bouts was individual. The subjects were allowed to start an exercising bout when their O_2 uptake dropped to a value of no more than 2.1ml/kg-1/min^{-1} different from that recorded before the start of the previous bout. The test was stopped when voluntary exhaustion occurred. The highest VO_2 record was taken as the subject's peak VO_2.

Supramaximal test (400m run)

The supramaximal test consisted of an all-out 400m track run. Subjects were allowed to perform their regular warm-up procedures and asked to run as if they were in a timed competition race. However, the test was not started until the subject's VO_2 was lowered to resting values (the same individual value recorded for each subject before the start of the submaximal test). Each runner performed the test run individually using proper competition footwear and clothing. The run was timed manually with a stopwatch. Although the subjects adopted a self-pace strategy, mean running speed measured during the test was used for all calculations. Earlobe capillary blood sample collections were made 3 minutes post run and every 2 minutes thereafter until the blood lactate concentration ([La]) levelled off. Whole blood lactate concentration was measured using an Accusport Lactate Analyser (Boehringer, Mannheim, Germany). Before each test this device was calibrated, using YSI 1530 Standard Lactate Solutions (2.5, 5 10 and 15mmol/L^{-1}), as systematic measurement errors have been described for it (MEDBØ et al., 2000). Oxygen uptake was also measured (breath-by-breath and then averaged at 10 second intervals) during this test with the Cortex Metamax I on which the aforementioned calibration procedures were performed.

Calculations of energy cost of running, accumulated oxygen deficit, aerobic fraction and anaerobic fraction of energy release

Energy cost of running (C_R) in the submaximal 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 2.3kg, C_r was corrected for total load (body mass plus 2.3kg). 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 a resting VO_2 measurement (zero speed VO_2). When the last bout of the submaximal test lasted less than 5 minutes, the VO_2 value was not included in the regression equation.

The linear regression equation calculated for each subject was used to extrapolate the accumulated O_2 demand (AO^{Demand}) required to perform a 400m run. As the accumulated O_2 uptake (AO^{uptake}) was measured during the 400m run, the AOD was calculated as the difference between the AO^{Demand} and the AO^{uptake}.

Energy cost of running during the supra maximal test was calculated by dividing the AO^{Demand} by the distance covered. The aerobic fraction of the energy elicited during the 400m run (E_{AER}) was obtained by dividing the AO^{uptake} by the AO^{Demand}. The anaerobic fraction of the energy elicited during the 400m run (E_{AN}) was obtained by dividing the AOD by AO^{Demand}.

Statistics

Data analysis and graphics were performed using an SPSS 10.0 and Sigma Plot 8.0 (SPSS Science, Chicago, USA) respectively. Simple linear regressions were used on all appropriate data. The correlation coefficient and the standard error of the regression were used as indicators of the fitness of the regression lines. Normality assumption of the distribution was checked with the Shapiro-Wilk test. A paired samples t-test was used to detect differences between the variable values in the two moments of assessment. In all statistical analyses, the significance threshold was set at $p \leq 0.05$. Data are presented as individual values or as means and standard deviations (means ± SD).

Results

The mean R of the VO_2-running speed regression lines was 0.988 ± 0.008 in the off-season phase (OSP) and 0.992 ± 0.006 in the summer preparation phase (SPP). The standard errors of the regressions were 1.25 ± 0.05 and 1.39 ± 0.05 $ml/kg^{-1}/min^{-1}$, in the OSP and SPP respectively. The subjects' mean peak VO_2 did not change significantly during the season, being 59.80 ± 5.80 and 58.75 ± 4.95 $ml/kg^{-1}/min^{-1}$, for the OSP and SPP respectively. The mean 400m performance times were 52.9 ± 0.9s in the OSP and 50.6 ± 1.5s in the SPP. The maximum VO_2 attained during the 400m run decreased significantly ($p \leq 0.05$) during the season and the mean values were 41.02 ± 8.15 and 37.25 ± 4.75 $ml/kg^{-1}/min^{-1}$ (corresponding to ~69% and ~63% of the subject's peak VO_2) for the OSP and the SPP respectively. Table 1 presents other measurements and estimations for the 400m run. Figures 1 and 2 present the kinetics of the VO_2 during the 400m run in the OSP and SPP respectively.

Discussion

The aims of this study were to compare the AOD, the energy cost of running and the anaerobic fraction of energy elicited during an all-out 400m track run performed by athletes in two phases of a training season (off-season phase and summer preparation phase).

The AOD estimated during the test runs did not change significantly during the season. It has been suggested that sprint-trained subjects present a greater AOD than endurance-trained or non-trained subjects (MEDBØ and BURGERS, 1990; SCOTT et al., 1991; WEYAND et al., 1994; NUMMELA and RUSKO, 1995). Moreover, others have observed an increased AOD after high-intensity training albeit with non-trained subjects (MEDBØ and BURGERS, 1990; RAMSBOTTOM et al., 2001; WEBER and SCHNEIDER, 2002). In the present study, the performance of the subjects in the 400m test runs improved significantly from 52.9 ± 0.9s in the OSP to 50.6 ± 1.5s in the SPP. Since this improvement was not matched by an increase in the AOD values, we may conclude that it was not due to an improvement in the anaerobic power and or capacity of the subjects. HEUGAS et al. (1997) evaluated the AOD of 400m runners during high-intensity treadmill running at two points of a training season and observed that the AOD decreased during the three-month period of assessment. In another study, HEUGAS and BRISSALTER (2000) found that during

Table 1: Mean (± SD) of the average running speed in the 400 m (V400), the blood lactate concentration post-run ([La]), the energy cost of running (C_R), the accumulated oxygen deficit (AOD), the aerobic (E_{AER}) and the anaerobic (E_{AN}) fractions of energy elicited in the off-season (OSP) and summer preparation (SSP) phases of testing

	V400 (m/s^{-1})	[La] ($mmol/L^{-1}$)	C_R ($ml/kg^{-1}/m^{-1}$)	AOD (ml/kg^{-1})	EAER (%)	EAN (%)
OSP	7.56±0.15*	13.8±0.9	0,220±0.004*	58.0±11.63	34±6*	66±6*
SSP	7.90±0.16*	15.5±1.6	0.202±0.003*	55.3±7.28	32±5*	68±5*
* p_0.05; ** p_0.01.						

Figure 1: Mean oxygen uptake and mean oxygen deficit during the 400m test run in the off-season phase

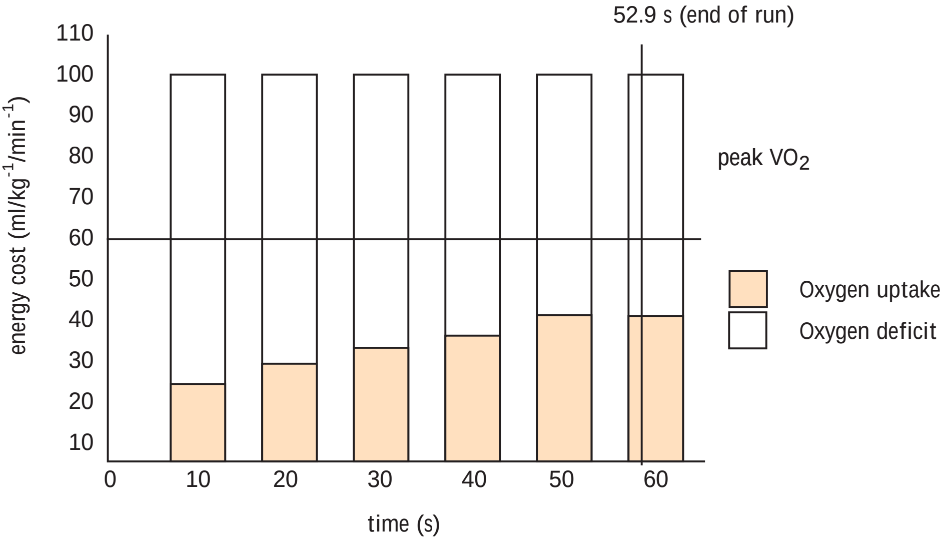
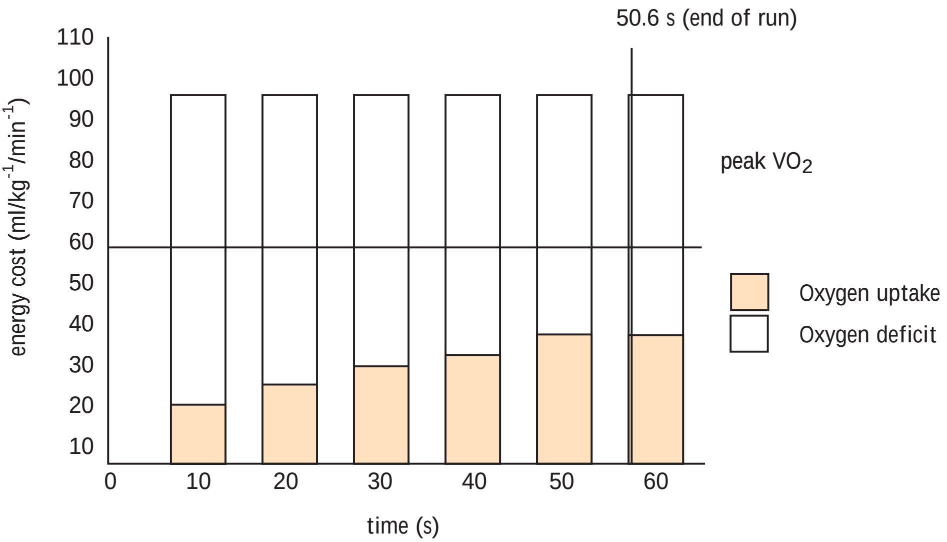


Figure 2: Mean oxygen uptake and mean oxygen deficit during the 400m test run in the summer preparation phase



preparation for the Olympic Games runners significantly improved their 400m performance without a significant change on AOD. Moreover, they did not find any association between AOD and performance in the 400m. The same absence of correlation in 400m runners was observed in by REIS et al. (2004).

The estimations of the anaerobic contribution to the total energy release (E_{AN}) in the present study were 66 ± 6% in the OSP and 68 ± 5% in the SPP. These values are within the range suggested by metabolite-based estimations for the E_{AN} for a 400m run made by LACOUR et al. (1990) and for constant-intensity treadmill simulation of a 400m by

HILL (1999), 72% and 63% respectively. Studies on the AOD during 400m track runs have presented either larger (REIS et al., 2004) or smaller (DUFFIELD and DAWNSON, 2003) mean values than the results of the present study. The differences between the E_{AN} of the present study and others may be due to methodological issues (treadmill vs track running testing and respiratory vs metabolite-based estimations) or to the subjects' performance ability.

In the present study, the C_R decreased significantly ($p \leq 0.01$) from the OSP to the SPP. We have also observed a significant change ($p \leq 0.05$) in the anaerobic contribution to the total energy release (E_{AN}), from 66 ± 6% in the OSP to 68 ± 5% in the SPP. It has been suggested that the C_R may decrease after endurance training (BILLAT et al., 1999; MILLET et al., 2002; SAUNDERS et al., 2004). However, we have not found any study investigating the changes in the C_R induced by sprint training. In the present study it seems that the improvement in 400m performance can be explained by a lower C_R and a higher E_{AN}. Since the E_{AN} is calculated by dividing the AOD by the total C_R during the run and the total C_R decreased from the OSP to the SPP, a larger E_{AN} could have resulted from an increased AOD. However, this was not the case in the results of the present study. The larger E_{AN} during the 400m run in the SPP resulted from a change on energy demand during the second test.

Concomitant with a lower energy demand, we observed that the VO_2 was lower throughout the 400m run in the SPP. The behaviour of the VO_2 during both tests presented a similar profile (rising progressively until the end of the run) but the mean values were lower during the second test in each of the 10-second intervals that were analysed (see Figures 1 and 2). Indeed, the maximum VO_2 attained during the 400m test run decreased significantly ($p \leq 0.05$) during the season and the mean values represented ~69% and ~63% of the subjects' peak VO_2) for the OSP and the SPP respectively. Additionally, the subjects' peak VO_2 in the OSP and SPP was similar. During laboratory treadmill high-intensity tests, VO_2 attains values above 90% of the subject's peak VO_2 within one minute of exercise (HEUGAS et al., 1997; SPENCER and GASTIN, 2001). However, these were generally constant-intensity tests. It is possible that the extremely high energy demand during the initial phase of an all-out test may cause a respiratory response that delays the VO_2 response (REIS et al., 2004).

The mean blood lactate values in the present study were lower than the observations of LACOUR et al. (1990), similar to those of DUFFIELD and DAWNSON (2003) and REIS et al. (2004) and higher than other reports for 400m runners tested during horizontal treadmill running (WEYAND et al., 1994) or inclined treadmill running (HEUGAS and BRISSWALTER, 1995). Since the performance level of the subjects in the DUFFIELD and DAWNSON (2003) and REIS et al. (2004) studies are closer to those of the present study, the differences to the remaining studies may result from different anaerobic abilities. Others have previously suggested that an improvement in the performance of 400m runners is concomitant with an increased lactate production (SCHNABEL and KINDERMANN, 1983; JACOBS et al., 1987; NEVILL et al., 1989; LACOUR et al., 1990; MERO et al., 1993, REIS et al., 2004). Indeed, we have observed a small increase in the blood lactate of the subjects from OSP to SPP. However, since the differences were not significant, we cannot support the results of the abovementioned studies.

Conclusion

In summary, the main findings of the present study were that a significant improvement in 400m performance was matched by a significant decrease on the CR and in the VO_2 during the run. The results suggest that factors other than the anaerobic energy production may influence performance in 400m track runs. Hence, more studies are warranted to verify the sensitivity of the AOD and of the EAN to differentiate the performance of trained sprinters. If sprinters can improve their running economy during high-speed running, then the lower VO_2 that we have observed during the 400m test run in the SPP could be a response to a decrease in the energy demand. This suggests that athletes may improve their performance in the 400 metres by improving their running economy during high-speed running and highlights the need to master an effective running technique. It also suggests that running technique should be trained all year round in order to avoid significant changes, such as the observations of the present study.

The question whether this improvement in high-speed running economy results from the use of general or specific running technique exercises was not addressed by this study. However, we do know that 400m runners typically start their season with larger volumes of low-intensity running. It is possible that such training intensities may influence the yearly development of the most effective (economical) technique. Therefore, the use of high-intensity specific exercises may be necessary to avoid such effects. We recommend that further studies on this issue should test athletes every 2 or 3 months during a training season to understand the changes in running economy in the several preparation periods of a season.

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