Recent research into the relative contributions of the three energy systems to high intensity exercise suggests that the contribution made by the aerobic energy system has, in the past, been underestimated. However, current coaching literature still takes little note of this research, with its obvious importance for training methodology. The traditional view has been based on faulty methods of research. The latest research uses the more accurate Accumulated Oxygen Deficit method, which takes into account individual efficiency relationships in calculating the relative aerobic and anaerobic energy system contribution. Using this method, the authors conducted a treadmill experiment with small groups of sprinters and middle distance runners, simulating high intensity runs over 400, 800 and 1500 metres. The resulting data indicated that, over all these race distances, the role played by the aerobic energy system is more important than that which has long been accepted.

1 Introduction

For many years it has been accepted that the body's three classified energy systems predominate within set time frames during high intensity exercise. For example, it has been published that the ATP-CP system supplies virtually all the energy required during the initial 10 seconds of exercise, the lactic acid system contributes the majority of energy during the time period from 10 seconds to 3 minutes and the aerobic system increasingly predominates from this time forth (McArdle, Katch and Katch 1991; Roberts 1991; Rushall and Pyke 1993).

Recent research suggests that the relative contribution of the aerobic energy system to high intensity exercise has been continually underestimated (Gastin et al. 1995; Medbo and Tabata 1989). Traditionally, it has been accepted that the aerobic energy system responds slowly to the demands of short duration high intensity exercise, such as in sprint and middle distance running.

While the above mentioned studies do not question the established interaction between the energy systems, they do question the time course of this interaction. The relative contribution of the energy systems during high intensity running (400 to 1500 metres) has implications for the design of training programmes.

This study is of significance, since much of the research completed in the past has employed methods, such as the oxygen debt method, which may overestimate the anaerobic energy system contribution. Therefore, the basic principles which are used to plan the athlete's training are influenced by potentially inaccurate information. If the contribution of the aerobic system has been underestimated, more attention must be given to the development of this system. This study is unique, in that it evaluated the aerobic and anaerobic energy system contributions over specific running distances rather than over selected time periods of exercise.

In relation to the information regarding energy system contribution during high intensity exercise, the findings of several studies in recent years (Gastin et al. 1995; Medbo and Tabata 1989;
Table 1: Descriptive characteristics of the subjects

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Height [cm]</th>
<th>Weight [kg]</th>
<th>Peak O₂ uptake [l/min]</th>
<th>[ml/kg/min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST (N=4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean ± SEM</td>
<td>30 ± 2</td>
<td>178 ± 4</td>
<td>79 ± 1</td>
<td>51 ± 3</td>
</tr>
<tr>
<td>Range</td>
<td>25-34</td>
<td>175-182</td>
<td>68-68</td>
<td>39-42</td>
</tr>
<tr>
<td>MDT (N=5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean ± SEM</td>
<td>23 ± 3</td>
<td>176 ± 1</td>
<td>71 ± 3</td>
<td>65 ± 2</td>
</tr>
<tr>
<td>Range</td>
<td>19-33</td>
<td>173-180</td>
<td>68-61</td>
<td>48-59</td>
</tr>
</tbody>
</table>

ST = Sprint trained, MDT = Middle distance trained

Withers et al. (1991) have not been recognised in the non-scientific literature. For example, the Australian Sports Commission's publication "Better Coaching: Advanced Coach's Manual" (1991) states that the anaerobic energy systems predominate in maximal exercise of less than 2 minutes. Therefore, if this was the case, a maximal 800 metres run of 2 minutes duration would be approximately 50% aerobic.

This belief may be due to the methodology employed in relevant research since the 1970's (i.e. the oxygen debt method and the oxygen deficit method which assume a constant mechanical efficiency).

Recent research, which utilises more appropriate methods to address these issues, suggests that the relative contribution of the aerobic and anaerobic energy systems is approximately equal during maximal exercise of 60sec duration (Gastin and Lawson 1994; Herman and Medbo 1974; Medbo and Tabata 1989; Withers et al. 1991).

Running was selected as the mode of exercise during this study as, in general, sprinters and middle distance track runners predominantly perform quality efforts at high intensities during training and devote little time to developing the aerobic energy system. It was decided to simulate the 400, 800 and 1500 metres events, as they reflect a range of durations where the intensity of exercise is high and the energy contribution considered significantly anaerobic.

The purpose of this study was, therefore, to evaluate the aerobic and anaerobic energy system contribution during exhaustive treadmill running that simulates the speeds and durations of the 400, 800 and 1500 metres events.

2 Methods

2.1 Subjects

All subjects in the study were males and currently competing at club or state level (Table 1).

The sprint group (n=4) consisted of specialists in the 200 and 400 metres track events, who could run 400 metres in 50-53sec, at the time of testing.

The middle distance athletes (n=5) specialised in the 800 or 1500 metres events and could run these events in the respective times of 1:53 to 2:00min and 3:55 to 4:07min, at the time of testing. Testing was conducted during the athlete's specific preparation training phase.

The procedure used to evaluate the aerobic and anaerobic system contribution to the energy demand of exhaustive treadmill exercise was the accumulated oxygen deficit (AOD) method of Medbo et al. (1988). This method is currently considered the most accurate (Gastin 1994).

2.2 Protocol

Subjects were required to attend the laboratory on two (sprint athletes) or three (middle distance athletes) separate occasions. During the initial visit a series of discontinuous treadmill runs (n=6) was completed, to establish individual running economy. The treadmill runs, from 11 to 16km/h, were separated by rest periods increasing progressively from 5 to 9min. Steady state oxygen uptake was determined by averaging the oxygen uptake during the last 2min of each 6min submaximal run. The relationship between steady state oxygen and treadmill speed was extrapolated and used to estimate energy demand, or oxygen cost, during supramaximal treadmill exercise.

A progressive incremental protocol, elevating treadmill gradient 2% per minute until exhaustion, was selected as the mode of exercise during this study as, in general, sprinters and middle distance track runners predominantly perform quality efforts at high intensities during training and devote little time to developing the aerobic energy system. It was decided to simulate the 400, 800 and 1500 metres events, as they reflect a range of durations where the intensity of exercise is high and the energy contribution considered significantly anaerobic.

The purpose of this study was, therefore, to evaluate the aerobic and anaerobic energy system contribution during exhaustive treadmill running that simulates the speeds and durations of the 400, 800 and 1500 metres events.

Table 2: Oxygen deficit, aerobic metabolism and other calculated variables comparing the 400, 800 and 1500 metres running events

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>400m</td>
<td>170 ± 12%</td>
<td>41.9 ± 4.2</td>
<td>46 ± 4%</td>
<td>42.7 ± 3.8</td>
<td>0.94 ± 0.07</td>
</tr>
<tr>
<td>800m</td>
<td>112 ± 5%</td>
<td>44.9 ± 6.6</td>
<td>69 ± 4%</td>
<td>33.4 ± 2.8</td>
<td>0.74 ± 0.07</td>
</tr>
<tr>
<td>1500m</td>
<td>102 ± 4%</td>
<td>47.4 ± 6.9</td>
<td>83 ± 3%</td>
<td>33.4 ± 3.6</td>
<td>0.63 ± 0.006</td>
</tr>
</tbody>
</table>

Significant comparisons (P<0.05); *) = 400m vs 800m; **) = 400m vs 1500m; ***) = 800m vs 1500m

Values are mean ± SEM.
tion, followed these submaximal runs and was used to determine peak oxygen uptake ($V_{O_2}^{\text{peak}}$).

On separate days, subjects were asked to complete an exhaustive treadmill run at a velocity which was approximate to their running speed during either 400m running (sprint athletes) or 800 or 1500m running (middle distance athletes), in a counterbalanced fashion. These performance times were estimated from the athlete’s best training times in the two months prior to testing.

Due to the fast treadmill speeds required to simulate the selected running events, a harness body support system was used as a precautionary safety measure.

Expired respiratory gases were analyzed during all tests, using an automated on line metabolic analysis system (Sensormedics Vmax 29), in the breath by breath mode.

Accumulated oxygen deficit, which provides a quantitative measure of anaerobic energy release, was taken as the differences between the estimated oxygen cost of the exercise effort and the actual oxygen uptake. Relative aerobic and anaerobic energy system contribution was calculated directly from this data, although no correction was made for the contribution of stored oxygen. A custom built Austradex Hercules Mark 11 treadmill was used during the study.

### 2.3 Data analysis

All data was downloaded into a spreadsheet (Excel 5.0) and a scientific graphics software programme (Delta Graph Pro 3.5, DeltaPoint).

**Oxygen cost [ml/kg]**

![](image)

**Figure 1:** Aerobic and anaerobic contribution to the total oxygen cost of the 400, 800 and 1500m runs Data are mean values.

Individual running economy was established, using linear regression, from the relationship between steady state oxygen uptake and treadmill speed.

Data obtained during supramaximal treadmill running was averaged over 10sec intervals and the oxygen deficit, taken as the difference between actual and predicted oxygen uptake, was accumulated with time. From this information, specific energy system models for events ranging from 400 to 1500 metres were developed.

Dependent and independent t-tests were used, to assess differences in absolute and relative aerobic and anaerobic energy release between the three simulated running events (i.e. 400, 800 and 1500 metres).

### 2.4 Results

The aerobic contribution to the total energy demand became significantly greater as the duration of the running trial increased (Table 2).

*Figure 1* shows that the total oxygen cost of the 400, 800 and 1500 metres trials appears to be equal to the sum of a constant anaerobic component plus an aerobic component proportional to the duration of the exercise effort.

No significant differences in AOD were found between the three trials, despite significant differences in run durations.

*Figure 2* shows the mean oxygen deficit and oxygen uptake in 10 second time intervals for the 400, 800 and 1500 metres running trials. The higher mean exercise intensity with shorter exercise duration is evident in this figure.

It can also be seen that the sprint athletes obtained a higher percentage of the $V_{O_2}^{\text{peak}}$ during the 400 metres trials (98%) than the middle distance athletes during both the 800 and 1500 metres trials (90% and 94% respectively).

The relative aerobic and anaerobic contributions to the total energy demand of the three running trials, in 10 second time intervals, is plotted in *Figure 3*.

It is evident that, in the 400, 800 and 1500 metres runs, at some point between the 20 to 30 second time period, the relative contribution from both energy systems was equal. Therefore, after this time in all running trials, the energy release was predominantly aerobic.

### 3 Discussion

The major finding of this study is that the relative contribution of the aerobic energy system during high intensity running is significantly greater than is suggested in both the scientific and lay literature.
The traditional view of the 1970’s and 80’s, that the aerobic energy system responds slowly to the demands of short duration high intensity exercise, is not supported by the present study.

This is demonstrated by the fact that the percent VO₂ peak reached in the first 30 seconds for the 400, 800 and 1500 metres runs was 94, 69 and 59% respectively.

Current texts which are used to teach coaches and exercise specialists (MCARDLE, KATCH and KATCH 1991, RUSHALL and PYKE 1993) unfortunately still present a view that is based on obsolete data and the use of inappropriate methodology with which to access energy system contribution.

For example, the work of McARDLE, KATCH and KATCH (1991) still presents this traditional view, as it suggests that, during 2 minutes of maximal exercise, about 50% of the required energy is supplied aerobically.

This is significantly less than the figure obtained in the 800 metres trials of the current study (see Table 2).

The results of the present study, however, do support the findings of recent investigations.
conducted in cycling (Craig et al. 1993; Gastin and Lawson 1994; Gastin et al. 1995; Medbo and Tabata 1989; Withers et al. 1991) and running (Hermanse and Medbo 1984).

These studies, like the present study, used the AO0 method, which determines an individual efficiency relationship to calculate aerobic and anaerobic energy system contribution.

The relative aerobic energy contribution during 60sec of exhaustive exercise has been reported to be 47-51% (Gastin and Lawson 1994; Hermanse and Medbo 1984; Medbo and Tabata 1989; Withers et al. 1991).

This is similar to the 400 metres trials of the present study, which were slightly shorter in duration (see Table 2).

Figure 3: Relative contribution of the aerobic and anaerobic energy systems in 10 second intervals for the 400, 800 and 1500m runs

Data are mean ±SEM.
During high intensity exercise of 120 to 150sec duration, 63-65% of the total energy contribution has been found to be aerobic (Mebo and Tabata 1989). This can be compared to the 800 metres trials of this study, which were similar in duration (see Table 2).

Craig et al. (1993) reported that the aerobic contribution of exhaustive cycling lasting 270sec was 84%, which figure is very similar to that found in the 1500m trials, which were slightly shorter in duration (see Table 2).

In light of the foregoing, it is suggested that the aerobic contribution to the total energy demand of high intensity running is significantly greater than that presented in the traditional beliefs that date back to the early 1970's.

This finding is of importance, since the traditional view of the aerobic energy system adapting slowly to the demands of short duration high intensity exercise is still being taught to exercise specialists and athletic coaches.

Thus, the training of sprint and middle distance athletes is, to a certain extent, not programmed sufficiently towards improving the contribution of the aerobic energy system.

The difference in the methodology used to determine energy system distribution is the major reason for the inconsistency in reported relative aerobic energy contribution throughout the last 20 years.

The oxygen debt method has been shown to overestimate the anaerobic contribution (Hermansen 1969), while the AOD method which assumes a constant mechanical efficiency has been discredited, due to large individual variations in efficiency relationships (Mebo et al. 1988).

The use of the AOD method which determines an individual efficiency relationship, developed by Mebo et al. (1988), is suggested, in order to minimise any underestimation of the oxygen cost that may result from a decrease in efficiency at supramaximal exercise intensities (Gastin et al. 1995).

In accepting the results from this study, the differences between treadmill and track running should be noted. This is a limitation, since all performance trials were conducted at a relatively constant velocity, which is dissimilar to the typical race pattern (i.e. variable running speeds), and no wind resistance is encountered on the treadmill.

4 Practical Application

Perhaps the most important information, from a coaching perspective, is to be gained from the energy system patterns or models of the 400, 800 and 1500 metres running events.

Firstly, the relative exercise intensities (%VO_2 peak) of the 400, 800 and 1500 metres runs were 170, 112 and 102% respectively. This and other factors may vary with athletes of a more elite standard. One point of particular interest is the fact that the sprint athletes achieved a higher percentage of their VO_2 peak during the 400m runs than the middle distance athletes during their longer, more aerobic events.

Although the sprint athletes reported a significantly lower VO_2 peak than their middle distance counterparts, the results still suggest that the aerobic contribution is very important during the 400 metres event. This, along with the fact that the relative aerobic contribution during the 400m trials was found to be 46%, is sufficient reason for these athletes to devote more of their training towards developing their aerobic energy system.

The oxygen cost/energy demand of the three simulated events is presented in Figure 1. It is evident that the quantity of anaerobic energy used in the 400, 800 and 1500 metres runs was very similar. Therefore, the remaining energy requirements for the three runs were supplied via the aerobic energy system.

As the anaerobic energy available is limited (hence the term "anaerobic capacity") it must be used optimally and efficiently during each event. For example, if an 800 metres athlete ran a race at the intensity of a 400m run, midway through he would exhaust his anaerobic capacity and would have to slow down considerably, in order to finish the event. This may explain why, during 800 and 1500m events, some athletes who speed away from the field during the early part of the race often drop off the pace drastically in the latter stages.

In assessing the two middle distance running events (Figure 2), it can be seen that, after the first 60sec of exercise, oxygen uptake plateaux somewhat; after this, mean oxygen uptakes of approximately 89 and 91% of VO_2 peak were maintained (on average 60sec and 180sec respectively).

These figures are very similar and may explain partially why more athletes seem to double up successfully at the 800 and 1500 metres than at the 400 and 800 metres.

The energy system interaction graphs (Figure 3) suggest that, by the 30 second time period for the three runs, a greater proportion of the energy is supplied aerobically.

This supports the findings of Gastin and Lawson (1994), who stated that energy system contribution is predominantly aerobic at approximately 30sec and beyond during a 90sec all out cycle test.
This finding dispels the belief that during very high intensity exercise, like a 400 metres race, the aerobic energy system contribution is limited.

Therefore, to train optimally for the high intensity running required for the 400, 800 and 1500 metres events, a fine balance must be struck between the development of the aerobic and anaerobic energy systems.

Given the importance of maintaining speed, an appropriate way to develop aerobic endurance may be via long interval/fartlek training rather than by an overemphasis of long slow distance running. For example, a long interval session might comprise 5 x 500m repetitions at 70% of 400m race pace, with a 300m recovery distance.

It would also make sense to emphasise this aerobic, overdistance work during preparation phases of training, while concentrating on more traditional forms of speed work during the pre-competition/competition training phase.

Based on the results and associated evidence presented in this study the following conclusions have been drawn:

1) The relative contribution of the aerobic energy system during high intensity running is significantly greater than is suggested in current teaching and coaching literature.

2) Long sprint and middle distance athletes should devote more of their training towards developing their aerobic energy system, without compromising their anaerobic energy system.

REFERENCES


