The aerobic mechanism in the 400 metres

By Enrico Arcelli, Marina Mambretti, Giuseppe Cimadoro, Giampiero Alberti

ABSTRACT

The 400m is generally considered to be a highly anaerobic race, but the findings of various researchers on the percentage contributions of anaerobic and aerobic energy mechanisms are not consistent. Drawing on a selection of publications, this article looks at how the energetic characteristics of the event are studied and explains the reasons behind the variation in findings. It considers 1) differences between men and women athletes, 2) differences between sprinter and endurance type athletes, 3) the influence of different methodologies and 4) differences caused by the performance level of the athletes studied. The authors find that performance capacity represents the most important quantitative factor for explaining the different percentages of intervention of the energy mechanisms. They also look at oxygen consumption and suggest an increase in pH level in the first 150-200m inhibits Type II muscle fibres from using the aerobic mechanism in the later stages of the race.

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In the past, the 400 metres has generally been considered to be a highly anaerobic race. LACOUR et al. (1990), for example, estimate the aerobic component at just 28%, NEWSHOLME et al. (1992), state that only 25% of the energy comes from the aerobic mechanism and FOSS & KETEYAN (1998) even go so far as to talk of an 18% aerobic contribution. However, some authors have shown higher values for the aerobic quota. NUMMELA & RUSKO (1995) and HILL (1999), for example, both calculate minimum values for the aerobic factor at 37%, for DUFFIELD et al. (2005) it is 41-45% and for WYAND et al. (1994) the intervention of the aerobic mechanism is actually more important in terms of percentage (equivalent to 64-70%) than the anaerobic mechanisms (see Table 1).

In this article we make an in-depth examination of the current knowledge of the energetic characteristics of the 400m and try to understand why the different researchers who have been concerned with the subject furnish very different data on the contribution of the aerobic mechanism.
Specifically, we look at 1) how the various researchers have studied energetic characteristics in the event; 2) the reasons why the percentages of aerobic and anaerobic contributions are considered different by the various authors; 3) oxygen consumption during the 400m and, in particular, why after the initial phase of 400m race consumption of oxygen has a slight tendency to come near to maximum while it tends to reduce in the final phase of the test, as some authors maintain.

**How various researchers have studied energetic characteristics in the 400m**

Researchers have employed various methods to determine energetic characteristics in the 400m. LACOUR et al. (1990), for example, have calculated the total energetic expenditure by measuring 400m runners’ peak blood lactate after the race and by estimating both the amount of oxygen used and the amount of alactacid mechanism used on the basis of data in the literature.

WEYLAND et al. (1993), NUMMELA & RUSKO (1995) and SPENCER & GASTIN (2001) simulated a 400m race on the treadmill using the method suggested by MEDBO et al. (1988) to calculate the “accumulated oxygen deficit”. Thus, in each athlete, the energetic cost of the race was measured at various sub-maximal speeds, and by extrapolation, the “estimated cost” at the speed at which the test was run. At this speed, the effective oxygen consumption of the athlete represents the aerobic component while the difference between the “estimated cost” and effective oxygen consumption, in fact, constitute what is defined as “accumulated oxygen deficit”, which corresponds to the anaerobic component.

HILL (1999), in turn, made athletes run on the treadmill to evaluate oxygen consumption. At the end of a 400m race run by the same athletes, he obtained blood lactate values in order to calculate the intervention of the glycolitic anaerobic mechanism.

Finally, DUFFIELD et al. (2005) made 11 men and 5 women do a test run on a 400m track, during which they measured effective oxygen consumption with the Cosmed K4 and determined the “accumulated oxygen deficit”. At the same time, they calculated the anaerobic intervention on the basis of the blood lactate levels taken after the test and of estimate of the energy derived from phosphocreatine. In practice, these authors simultaneously evaluated 400m runners with the criteria previously used by the other authors mentioned.
Reasons why the percentage of the aerobic contribution is considered different by different authors

Differences between men and women
For the purposes of establishing a greater or lesser level of intervention of the aerobic mechanism, we must first take into account whether the 400m runners are men or women. ARCELLI (1995) showed that when two athletes, one male and the other female, obtained identical results in the 400m (for example 48 sec), the woman produced more lactic acid. Thus, since the energetic expenditure (expressed in ml/kg⁻¹) is similar in both athletes, and in the woman there is a greater quantity of energy derived from the glycolitic mechanism, the percentage of aerobic work turns out to be higher in the man.

However, this is not true when considering performances that are not equal from a chronometric point of view but do have a comparable value, so as, for example, to occupy similar positions in male and female rankings, respectively, on a national and world level. WEEDEDAY et al. (1994), for example, indicate values for aerobic intervention that are of 64-67% in men and 66-70% in women, for whom the aerobic mechanism thus turns out to be more important than for men. HILL (1999) gives the aerobic mechanism 37% of the energetic contribution in men and 38% in women. In turn, DUFFIELD et al. (2005) show the aerobic contribution as equal to 41% in males and 45% in females. With all things considered, it can be said that the consensus of all of the authors we have referred to is that in the 400m women athletes use a slightly higher percentage of aerobic energy (from +1% to +4%) when compared to men athletes (see Table 2).

Differences between sprinters and endurance athletes
The physiological characteristics of the athletes studied certainly influence the findings on the degree of intervention of the energetic...
mechanisms. In fact, “sprinter” type athletes (e.g. the ones who have good results in 200m) have greater anaerobic tendencies and hence derive a lower percentage of energy from the aerobic mechanism. The converse is true for runners who are more inclined to longer distances through genetics or training. WEYLAND et al. (1994), for example, show that in sprinters the contribution of the anaerobic mechanism is equal to 36% in men and to 34% in women athletes; however, in endurance athletes these authors determined the contribution to be 33% in men and 30% in women. In subjects that obtained 400m times that were approximately equal, NUMMELA & RUSKO (1995) arrived at an aerobic contribution of 37.1% in sprinters (average time 49.5 ± 6.0 sec) and 45.6% in endurance athletes (average time 49.4 ± 5.3 sec). As can be seen in Table 3, the aerobic mechanism intervention has been found to be 3-8% higher in the athletes who come from longer events.  

Influence of methodologies used

The criteria used to calculate the total energy expenditure and the intervention of the energetic mechanisms are also important. DUFFIELD et al. (2005) obtained values for the aerobic contribution that turned out to be higher when measured with the “accumulated oxygen deficit” method (41.9% in men and 44.5% in women) in comparison to data derived from evaluation of the blood lactate and estimation of phosphocreatine consumption (39.2% in men and 37.0% in women). The difference between the two methods was 6.1% in men and 7.5% in women respectively (see Table 4).  

According to BANGSBO (1996), the “accumulated oxygen deficit” method tends to underestimate the “estimated cost” in high intensity tests, which the 400m can be considered. In this way, the percentage of aerobic intervention was underestimated while the percentage of anaerobic intervention was underestimated. Moreover, it is entirely probable that in the final stretch of the 400m, there is an increase in the cost of the run.

HILL (1999) states that in laboratory experiments on the treadmill (as in NUMMELA & RUSKO, 1995, SPENCER & GASTIN, 2001, and WEYLAND et al., 1993) athletes are less motivated than in races and it is quite likely that this enables them to obtain the maximum intervention of the aerobic mechanism but not of the anaerobic mechanism. This point could also apply to the findings of DUFFIELD et al. (2005), who evaluated lactate production in runners during a test on the track that simulated a race but that was not competition. It should be noted that only LACOUR et al. (1990) and HILL (1999) evaluated lactate production in race conditions.  

Differences caused by performance level

At this point, we can establish how much influence the different performance levels of the athletes studied have in determining the different contributions of the energetic mechanisms. Table 5 shows various data in the literature for male and female 400m runners. For the women, when performance in the 400m gets worse, there does not seem to be a corresponding increase in the percentage of aerobic work. However, in the case of the

<table>
<thead>
<tr>
<th>Method</th>
<th>Subject Group</th>
<th>Aerobic Contribution</th>
<th>Anaerobic Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accumulated oxygen deficit</td>
<td>Men</td>
<td>41.9%</td>
<td>58.1%</td>
</tr>
<tr>
<td>Accumulated oxygen deficit</td>
<td>Women</td>
<td>44.5%</td>
<td>55.4%</td>
</tr>
<tr>
<td>Lactate + phosphocreatine</td>
<td>Men</td>
<td>39.2%</td>
<td>60.8%</td>
</tr>
<tr>
<td>Lactate + phosphocreatine</td>
<td>Women</td>
<td>37.0%</td>
<td>63.0%</td>
</tr>
</tbody>
</table>
men, taking into account that the values were calculated with dissimilar criteria and with greater inclinations towards sprinting or towards endurance tests, it can be noted that the better the results, the lesser the aerobic contribution.

In any event, this result becomes more evident if, based on the literature on the subject, a theoretical calculation of the energetic characteristics in terms of the times obtained for the 400m is carried out, as indicated in Table 6.

In Table 6 it is possible to see that the anaerobic contribution (of which the predominant part is glycolitic) falls rapidly with a decrease in the 400m performance level of the subject athletes. In fact, the reduction is greater than the decrease in the total expenditure. Passing, for example, from a time of 44 sec to a time of 48 sec, the total expenditure falls from 119.2 to 104.4 ml/kg⁻¹, a percentage fall of 12.4%. At the same time, the anaerobic work carried out passes from 90.1 to 70.1 ml/kg⁻¹, a reduction of 22.2%. If, instead, the performance goes from 48 to 52 sec, the total expenditure falls from 104.4 to 93.4 ml/kg⁻¹, (a fall of 21.6%), while the anaerobic work goes from 70.1 to 53.2 ml/kg⁻¹ (a fall of 41.0%). At the same time, the aerobic contribution increases as a consequence of the extended duration of the race, being 24% for a performance of 44 sec, 33% for 48 sec and 43% for 52 sec.

In the first moments of a 400m race the runner utilises mainly anaerobic mechanisms, since the quantity of oxygen he/she can manage to use is limited, but as the time of physical exertion is prolonged the use of oxygen is increased.

In other words, it happens that on the one hand, the faster athlete produces more lactate and on the other, has less possibility of using the aerobic mechanism. Thus for

<table>
<thead>
<tr>
<th>Author(s) and Subject Group</th>
<th>Publication Date</th>
<th>Average performance for the 400m (sec)</th>
<th>Aerobic Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Male Subjects</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lacour et al.</td>
<td>1990</td>
<td>45.48-47.46</td>
<td>28.0%</td>
</tr>
<tr>
<td>Hill</td>
<td>1999</td>
<td>49.3</td>
<td>37.0%</td>
</tr>
<tr>
<td>Spencer and Gastin</td>
<td>2001</td>
<td>49.3</td>
<td>43.0%</td>
</tr>
<tr>
<td>Nummela &amp; Rusko (endurance athletes)</td>
<td>1995</td>
<td>49.4</td>
<td>45.6%</td>
</tr>
<tr>
<td>Nummela &amp; Rusko (sprinters)</td>
<td>1995</td>
<td>49.5</td>
<td>37.1%</td>
</tr>
<tr>
<td>Weyand et al. (sprinters)</td>
<td>1994</td>
<td>50.5</td>
<td>64.0%</td>
</tr>
<tr>
<td>Reis &amp; Miguel</td>
<td>2007</td>
<td>50.6</td>
<td>32.0%</td>
</tr>
<tr>
<td>Duffield et al.</td>
<td>2005</td>
<td>52.2</td>
<td>41.3%</td>
</tr>
<tr>
<td>Weyand et al. (endurance athletes)</td>
<td>1994</td>
<td>58.5</td>
<td>67.0%</td>
</tr>
<tr>
<td><strong>Female Subjects</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weyand et al. (sprinters)</td>
<td>1994</td>
<td>57.9</td>
<td>66.0%</td>
</tr>
<tr>
<td>Duffield et al.</td>
<td>2005</td>
<td>60.2</td>
<td>44.5%</td>
</tr>
<tr>
<td>Weyand et al. (endurance athletes)</td>
<td>1994</td>
<td>70.6</td>
<td>70.0%</td>
</tr>
<tr>
<td>Hill</td>
<td>1999</td>
<td>71.2</td>
<td>38.0%</td>
</tr>
</tbody>
</table>
Calculating Energy Expenditure in the 400m

Energetic expenditure for 400m runners can be considered as equal to: \( C_{na} + C_a + C_k \).

In this sum:

- \( C_{na} \) is the non-aerodynamic cost of the run, that is, according to DI PRAMPERO (1985), the energy the athlete expends (1) to lift his/her body at every stride; (2) to accelerate the centre of gravity at every stride; (3) for friction at the point where the foot meets the ground; (4) for the internal work load; (5) for the muscular contractions necessary to maintain posture; (6) for the work of the respiratory muscles and the heart;
- \( C_a \) is the cost to overcome air resistance;
- \( C_k \) is the cost to accelerate the body in the start phase of the race.

The energetic expenditure of the run, including the non-aerodynamic component and the component to overcome air resistance \((C_{na} + C_a)\), is constant and expressed in ml of oxygen per kg of body weight and per km run. According to ARCELLI et al. (2006), it is equal to \(4 v^2 - 25 v + 175\), with \(v\) being the speed of the athlete in m/s\(^{-1}\).

Since the distance of the race is 400m (= 0.4 km):

- \( C_{na} + C_a = 1.6 v^2 - 10 v + 70\)

This cost is expressed in ml/kg\(^{1}\).

The cost to accelerate the body – also expressed in ml/kg\(^{1}\) – is, according to ARCELLI and DOTTI (2000), as follows:

- \( C_k = \frac{0.0957}{v^2}\).

The energetic expenditure to run 400m is sustained by the intervention of different energetic mechanisms. Thus:

- By \( L_ae \) we mean the energy derived from the aerobic energetic mechanism;
- By \( L_latt \), we mean the energy derived from the anaerobic lactacid mechanism.
- By \( L_latt \), we mean the energy derived from the anaerobic alactacid mechanism.

As far as \( L_latt \) is concerned, LACOUR et al. (1990) found that the lactate produced in the 400m race turned out to be equal to \(8.8 v - 54.3\), with \(v\) being the average speed in m/s\(^{-1}\). In this case, the formula these authors indicated for times between 45.45 and 49.07 sec is extrapolated for both slightly better and considerably worse performances. A caloric equivalent for lactate equal to 3 ml/kg\(^{1}\) for each 1 mmol/l\(^{-1}\) increase of blood lactate with respect to the basal count (considered as equal to 1 mmol/l\(^{-1}\)) must also be taken into account. \( L_latt \), then, must be considered as equal to 16 ml/kg\(^{1}\). \( L_ae \) is then calculated by difference, that is to say, by subtracting \( L_latt + L_latt \) from \( C_{na} + C_a + C_k \).

In this way, we derived the data used to construct the last four columns of Table 6.
him/her, anaerobic intervention is more important. The contrary is true of the slower runner, who uses a greater quantity of energy from the aerobic mechanism. The better the performance, the greater the anaerobic contribution and the lesser the aerobic contribution.

Performance capacity, therefore, definitively represents the most important quantitative factor for the purposes of explaining the different intervention of the aerobic mechanism.

Figure 1 shows the curve of the contribution of the aerobic mechanism for male runners in percentage according to performance times, calculated theoretically on the basis of what has been stated above and the data given in Table 5.

**Oxygen consumption during the 400m and maximum oxygen consumption**

Athletes never reach their maximum oxygen consumption (VO$_2$max) in the 400m. According to NUMMELA & RUSKO (1995), they have a peak oxygen consumption that is equal to 79% VO$_2$max; according to SPENCER & GASTIN (2001), they reach 89%; according to DUFFIELD et al. (2005), both men and women use 81.6%. NUMMELA & RUSKO

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**Table 6: Fall in the total energetic expenditure and anaerobic contribution with slower performances in the 400m (male athletes only)**

<table>
<thead>
<tr>
<th>400m performance (sec)</th>
<th>Energetic expenditure (ml/kg$^2$)</th>
<th>Anaerobic contribution (ml/kg$^2$)</th>
<th>Anaerobic contribution (%)</th>
<th>Aerobic contribution (ml/kg$^2$)</th>
<th>Aerobic contribution (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>44</td>
<td>119.2</td>
<td>90.1</td>
<td>75.6</td>
<td>29.1</td>
<td>24.2</td>
</tr>
<tr>
<td>46</td>
<td>111.1</td>
<td>79.7</td>
<td>71.7</td>
<td>31.4</td>
<td>28.3</td>
</tr>
<tr>
<td>48</td>
<td>104.4</td>
<td>70.1</td>
<td>67.1</td>
<td>34.3</td>
<td>32.9</td>
</tr>
<tr>
<td>50</td>
<td>98.5</td>
<td>61.3</td>
<td>62.2</td>
<td>37.2</td>
<td>37.8</td>
</tr>
<tr>
<td>52</td>
<td>93.4</td>
<td>53.2</td>
<td>56.9</td>
<td>40.2</td>
<td>43.1</td>
</tr>
</tbody>
</table>

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**Figure 1: Contribution of the aerobic mechanism in the 400m for male runners by race time according to selected authors (Note both Nummela & Rusko and Weyand et al. show separate data for sprinters and endurance athletes; the straight line shows the contribution of the aerobic mechanism according to performance time calculated theoretcly on the basis of data given in Table 3.)**
also found that after mid-race, oxygen consumption never tended to increase and that, in both in sprinters and endurance athletes, it even tended to reduce in the last stretch. According to REIS & MIGUEL (2007), in the course of a 400m race simulation, runners barely reached 63% of their maximum rate of oxygen consumption in the final part of the race.

In tests where VO$_2$max was determined during the run, higher values were reached. Thus it happened that, in the time phase in which the efficiency of oxygen contribution to the muscles increases, running speed is low or medium-low and in the muscles employed, Type I fibres (aerobic muscle fibres that can externalise reduced strength values) are mainly used. Only in the later phases of the race, when the intensity is already close to or above VO$_2$max and when the mechanisms that allow the arrival of oxygen in the fibres are already activated, do Type II fibres work intensively, and these fibres are on the average endowed with greater levels of strength. Instead, even at the start of the 400m, when the oxygen contribution to the fibres is still not very high, since the running speed is very high, a significant percentage of Type II fibres are called upon to work, both of the Sub-type IIa, as well as the Sub-type IIx (those that, in older terminology were called IIb); but the latter are not very resistant.

We think that the explanation for the fact that after 150-200m in competition the consumption of oxygen has a minimum or even zero tendency to increase and come close to VO$_2$max levels, and that it even tends to become lower in the final phase of the race (NUMMELA & RUSKO, 1995), is that many of the Type II fibres are placed “out of action” since they have arrived at a critical pH level. Thus, because of the inhibition of glycolysis enzymes, they cannot use the aerobic mechanism. This might also be the reason for the decrease in strength after the first 100m found by NUMMELA et al. (1992).

**Conclusion**

Both aerobic and anaerobic (alactic and lactic) mechanisms provide the required energy in the 400m. Many researches have tried to show the percentage of the total energy provided by these mechanisms but, unfortunately, their findings have diverged greatly.

We have identified several aspects that can affect the findings of research in this area. One of these is the gender of the athlete. Considering the same national and international ranking, women use the aerobic mechanism more than men. It is also important to consider the physiological abilities of a 400m runner. Sprint type athletes (e.g. the ones who have good results in the 200m) use anaerobic mechanisms more than those athletes who have higher aerobic abilities through genetics or training. Another significant aspect that can affect the obtained results is the different methodologies used in the research. Based on analytical evaluations of literature data, we have determined that the slower the performance, the greater the aerobic contribution and that performance level is the most important factor in the relative contribution of the several energetic mechanisms.

We also looked at how the oxygen uptake changes during the 400m. It does not reach the maximum value (VO$_2$max), and in the final part of the race it slightly decreases. One explanation is that the increased pH level caused by the anaerobic work done in the first part of the race inhibits the glycolysis enzymes and thus stops the Type II muscle fibres from using the aerobic mechanism.

Further analysis is required to understand the factors responsible for this reduction of oxygen consumption, and how the consumption can differ between different athletes.

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REFERENCES


