DETERMINANTS OF FIVE KILOMETRE RUNNING PERFORMANCE IN ACTIVE MEN AND WOMEN

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ABSTRACT

Previous studies of elite endurance athletes have suggested that success in distance running is attributable to the possession of a high maximal oxygen uptake (VO₂ max), the utilisation of a large fraction of the VO₂ max and to running economy. The purpose of the present study was to examine the relationships between these physiological characteristics and running performance in active but not elite men and women. Maximal oxygen uptake values were 57.6 ± 6.2 and 46.6 ± 4.8 ml.kg.⁻¹.min⁻¹ for the men and women respectively (p < 0.01). Running performance was assessed as a 5km time trial and the men completed this distance in 19.77 ± 2.27 min and the women in 24.44 ± 3.19 min (p < 0.01). Maximal oxygen uptake showed strong correlations (p < 0.01) with running performance (men, r = −0.85; women, r = −0.80) but there was only a modest relationship between running economy and performance (men, r = 0.39; women, r = 0.34). The results of the present study suggest that the faster 5km performance times recorded by the men were best explained by their higher VO₂ max values.

Key words: Maximal oxygen uptake, Running economy, Running performance, 5km run

INTRODUCTION

Many investigations reported in the literature have attempted to identify the physiological attributes associated with distance running success. The possession of a large maximal oxygen uptake (VO₂ max) has frequently been connected with successful running performance (e.g. Saltin and Astrand, 1967; Costill et al, 1973). Differences in running economy, which has been defined as the oxygen consumption for a given submaximal treadmill running velocity (Farrell et al, 1979), discriminate between individuals possessing similar VO₂ max values in terms of performance (Conley and Krahenbuhl, 1980). The ability to utilise a large fraction of the VO₂ max (Costill et al, 1971), the proportion of slow twitch fibres in the running musculature (Costill et al, 1976), and more recently the rate of accumulation of lactate in the plasma (Farrell et al, 1979) or blood (Sjödin and Jacobs, 1981) have also been recognised as factors which may determine distance running success. The purpose of the present study was to investigate the relationships between VO₂ max, running economy and running performance in a large group of active men and women, relatively few of whom were trained runners.

METHODS

The subjects recruited for these studies were final year Physical Education students and, in order to obtain a sufficiently large sample of the same population, the investigation was carried out over a four-year period. Measurements were made throughout the study by the same investigators using standard methods and laboratory instrumentation. Laboratory procedures involved the measurement of height and weight and the direct determination of maximal oxygen uptake. This was determined by a continuous incremental grade test (modified after Taylor, Buskirk and Henschel, 1955) on a motor-driven treadmill (Woodway, ELG2). The belt speed was 3.13 m.s⁻¹ for both men and women and expired air samples were collected every three minutes until the subjects indicated that they could continue for only one more minute, when a final one minute sample of expired air was taken. A second treadmill test was performed on a separate occasion to determine the oxygen cost of submaximal running. In this sixteen-minute test the subject ran on a level treadmill, the speed of which was increased at the end of each four-minute period. Expired air samples were collected during the final minute of each stage for the determination of oxygen consumption (VO₂), carbon dioxide production (VCO₂), and minute ventilation (VE) (Williams and Nute, 1983). Throughout each test the heart rate of the subject was monitored on an oscilloscope (Rigel) using suitably placed chest electrodes. Both laboratory tests were performed after subject familiarisation with treadmill running.

Running performance was assessed by a 5km time trial. Of the 124 subjects, 98 (55 men, 43 women) ran on the University athletic track and 26 (14 men, 12 women) ran on a flat, carefully measured 1km road course while construction work temporarily closed the track. Performance and lap times were recorded using digital stopwatches (Accusplit). Subjects of similar ability ran in groups of not more than six to encourage competition. Because of illness and injury some subjects did not complete all tests (VO₂ max, VO₂ submax, 5km run).

Simple correlation coefficients, linear regressions and t-tests were performed using the Minitab statistical package. Paired observations were used throughout each analysis. A t-test for independent samples was used to test for differences between the means for men and women.

RESULTS

The physiological characteristics of the men and women participating in this study are presented in Table I. The VO₂ max and VE max values of the men were 50.0% and 46.9% greater respectively (L.min⁻¹; p < 0.01) than those of the women, but there were no significant differences between the maximum heart rate values nor in the oxygen cost of submaximal running at the same velocity (Fig. 1). However, when running velocity was expressed as relative exercise intensity (%VO₂ max), there was a significant difference between the men and women (p < 0.01) (Table II).

When the results for the men and women were combined there was a strong correlation between VO₂ max and running performance (r = −0.89) (Fig. 2). Running performance, the estimated oxygen cost and estimated %VO₂ max utilised during the 5km run, together with

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TABLE I
Physiological characteristics of the male and female subjects
(Mean ± SD)

<table>
<thead>
<tr>
<th>Subject</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>VO2 max (ml.kg⁻¹.min⁻¹)</th>
<th>VE max (L.min⁻¹)</th>
<th>HR max (b.min⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Males</strong></td>
<td>n</td>
<td>69</td>
<td>69</td>
<td>69</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>178.3</td>
<td>72.7</td>
<td>4.2</td>
<td>57.6</td>
</tr>
<tr>
<td></td>
<td>± SD</td>
<td>6.4</td>
<td>9.0</td>
<td>0.6</td>
<td>6.2</td>
</tr>
<tr>
<td><strong>Females</strong></td>
<td>n</td>
<td>55</td>
<td>55</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>165.6**</td>
<td>59.9**</td>
<td>2.8**</td>
<td>46.6**</td>
</tr>
<tr>
<td></td>
<td>± SD</td>
<td>6.2</td>
<td>7.8</td>
<td>0.4</td>
<td>4.8</td>
</tr>
</tbody>
</table>

** significantly different between males and females p < 0.01

**Fig. 1:** The relationship between oxygen consumption and submaximal treadmill running velocity for men and women (men n = 58, women n = 44).

Running economy (%VO2 at 3.13 m.s⁻¹) and relative running economy (%VO2 max at 3.13 m.s⁻¹) are shown in Table II.

From individual lap times and the relationship between speed and VO2 for each individual it was possible to estimate oxygen consumption during the performance run. The men consumed more oxygen than the women in order to sustain their higher running velocity (p < 0.01) but there was no significant difference between the %VO2 max

**Fig. 2:** The relationship between VO2 max and 5km running performance for men and women (n = 124).

utilised by men and women during the 5km performance test. Both sexes ran the first and last 400 m faster than the intervening laps (Fig. 3).

**Fig. 3:** The estimated %VO2 max utilised during a 5km performance test for men and women (men n = 45, women n = 32).

**TABLE II**
Running performance, estimated oxygen consumption and estimated %VO2 max during a 5km run, together with running economy and relative running economy (at 3.13 m.s⁻¹) for the male and female subjects. (Mean ± SD)

<table>
<thead>
<tr>
<th>Subjects</th>
<th>5km time (min)</th>
<th>VO2 max (ml.kg⁻¹.min⁻¹)</th>
<th>Performance %VO2 max (ml.kg⁻¹.min⁻¹)</th>
<th>Running Economy %VO2 max (ml.kg⁻¹.min⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Males</strong></td>
<td>n</td>
<td>69</td>
<td>69</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>19.77</td>
<td>57.6</td>
<td>50.3</td>
</tr>
<tr>
<td></td>
<td>± SD</td>
<td>2.27</td>
<td>6.2</td>
<td>5.4</td>
</tr>
<tr>
<td><strong>Females</strong></td>
<td>n</td>
<td>55</td>
<td>55</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>24.44**</td>
<td>46.6**</td>
<td>41.3**</td>
</tr>
<tr>
<td></td>
<td>± SD</td>
<td>3.19</td>
<td>4.8</td>
<td>4.5</td>
</tr>
</tbody>
</table>

** significantly different between males and females p < 0.01
DISCUSSION

Maximal Oxygen Uptake (VO₂ max)

The VO₂ max values in the present study (Table I) were similar to those reported by Williams (1981) and Bland (1982) for men and women from a similar active population. The range of VO₂ max values in the present study was 42.6 to 76.5 ml.kg⁻¹.min⁻¹ for the men and 36.4 to 58.6 ml.kg⁻¹.min⁻¹ for the women. Maximal oxygen uptake values for elite male endurance athletes have been reported to be in the range 70-80 ml.kg⁻¹.min⁻¹ (Costill and Fox, 1969; Pollock, 1977; Davies and Thompson, 1979; Conley and Krahenbuhl, 1980; Sjödin and Schéle, 1982; Colquhoun, 1984). Similarly maximal oxygen uptake values in the order of 60 ml.kg⁻¹.min⁻¹ have been reported for elite female runners (Wilmore and Brown, 1974; Davies and Thompson, 1979; Hagan, Strathman, Strathman and Gettman, 1980; Wells, Hecht and Krahenbuhl, 1981).

It is generally accepted that men out-perform women in distance running events, for example Daniels and co-workers (1977) reported that “standards are about 10% slower for women in the 1500- and 3000-meter races and nearly 25% slower over the marathon distance”. The present study revealed the female time of 24.44 ± 3.19 min was 24% slower than the time recorded by the male subjects (19.77 ± 2.27 min). The current world records for 5km running show that the time for women (Budd, 14.80 min) is 13.9% slower than that for men (Aouita, 13.00 min).

“Women have approximately the same maximal oxygen uptake per kilogram fat-free body mass as men” (Åstrand and Rodahl, 1977, p. 379). However, male athletes possess a 20-25% higher VO₂ max than female athletes (Drinkwater, 1973). This 20-30% difference in VO₂ max (ml.kg⁻¹.min⁻¹) “is largely explained by their (female’s) higher content of adipose tissue” (Åstrand and Rodahl, 1977, p. 379). Normally active men have been found to possess 13.5 ± 5.8% body fat and normally active women 24.2 ± 6.5% body fat (Durnin and Rahaman, 1967). Male distance runners have been reported to have approximately 7.5% body fat (Costill et al, 1970) and their female counterparts to have 15.2% body fat (Wilmore and Brown, 1974).

Because of their smaller body size a woman’s heart is smaller, hence the maximum cardiac output (Q max) is limited by her smaller maximum stroke volume compared with a man (Wells, 1985, p. 20). The haemoglobin content of the woman’s blood is 10-15% less than that of the man and contains 6% fewer erythrocytes (Åstrand and Rodahl, 1977, p. 134) which results in a lower oxygen carrying capacity of the blood in women. Thus at the same absolute exercise intensity the woman must either deliver more blood to the working muscles or extract more oxygen from the blood supplied to that tissue (Wells, 1985). Expressed another way, the male requires 4.72 L of blood to transport 1.0 L of oxygen, whereas the female must pump 5.37 L of blood to transport the same quantity of oxygen. Thus differences in VO₂ max, and hence running performance, between men and women are largely explained by differences in maximum cardiac output, the oxygen carrying capacity of the blood and the higher proportion of adipose tissue in the female.

A strong correlation was found between VO₂ max and 5km time for both the men (r = -0.85; p < 0.01) and women (r = -0.80; p < 0.01). Similarly strong correlations have been reported by other investigators over different performance distances when athletes with a range of VO₂ max values have been used (Costill et al, 1973; Farrell et al, 1979 and Getchell et al, 1977). If the men and women in this study are treated as a single group then the correlation between VO₂ max and performance improves (r = -0.89); thus 79% of the variation in 5km performance in active men and women in the present study can be explained by variation in the maximal oxygen uptake.

The Oxygen Cost of Submaximal Running (VO₂ submax)

During submaximal treadmill running both men and women ran at three common speeds. There was no significant difference in the oxygen cost of submaximal treadmill running between the men and women at these speeds, suggesting that there are no sex differences in the aerobic demands of submaximal treadmill running (Fig. 1). This is consistent with results reported by Daniels (1977) and Mayhew et al (1979); although Bransford and Howley (1977) found a significant difference in the oxygen cost of running between untrained males and untrained females. These latter authors also reported that trained subjects were more economical, i.e. utilised less oxygen than untrained subjects at the same running speed.

Running Economy and Performance

Differences in running economy between individuals may be related to differences in running performance (Daniels, 1974; McMiken and Daniels, 1976; Conley and Krahenbuhl, 1980; Sjödin and Schéle, 1982). Conley and Krahenbuhl (1980) found that 65.4% of the variation in 10km performance times, in a group of athletes with similar VO₂ max values, was accounted for by the variation in running economy. Sjödin and Schéle (1982) also reported a strong correlation (r = -0.74; p < 0.05) between the oxygen cost of running at 4.47 m.s⁻¹ and performance over 3.2km. Costill and co-workers (1979) by comparison found only a modest correlation (r = -0.59; p < 0.05) between the oxygen cost of running at 4.17 m.s⁻¹ and performance over 3.2km. Costill and co-workers (1973), studying a group of runners with a range of VO₂ max values, also examined running economy at 4.47 m.s⁻¹ and commented that the oxygen consumption at that speed had “no apparent relationship to running performance”. In the present study the correlations between running economy at 3.13 m.s⁻¹ and performance were modest r = 0.39 (p < 0.01) and r = 0.34 (p < 0.05) for the men and women respectively. Treating the men and women as a single group, the correlation between running economy and performance was r = 0.24 (p < 0.05).

Sustained high speed running demands a high rate of energy expenditure and the utilisation of a highly developed oxygen transport system (Costill et al, 1973). The performance times (Table II) for the men and women in the present study represented an average “race pace” of 4.22 and 3.41 m.s⁻¹ (or 6.22 and 7.43 min per mile) respectively. The men consumed oxygen at an estimated rate of 50.3 ± 5.4 ml.kg⁻¹.min⁻¹ compared with an estimated 41.3 ± 4.5 ml.kg⁻¹.min⁻¹ for the women (p < 0.01). As may have been expected strong correlations were found between the estimated oxygen consumption at race pace (VO₂ max) and performance for both the male (r = -0.86; p < 0.01) and female (r = 0.79; p < 0.01) subjects. Similarly, Farrell and co-workers (1979) found a strong correlation (r = -0.87; p < 0.01) between oxygen consumption at 3.2km pace and performance. To paraphrase Farrell and co-workers (1979), 5km performance is closely related to the ability to maintain a large oxygen consumption, independent of what fraction this represents of the VO₂ max.
TABLE III

Maximal oxygen uptake, running performance [min], estimated oxygen cost and estimated %VO₂ max at 5km pace (m.s⁻¹) and at 3.13 (m.s⁻¹) for two 'economical' and two 'uneconomical' subjects

<table>
<thead>
<tr>
<th>Subject</th>
<th>V̇O₂ max (ml.kg⁻¹.min⁻¹)</th>
<th>5km time (min)</th>
<th>Performance V̇O₂ max (ml.kg⁻¹.min⁻¹)</th>
<th>% V̇O₂ max</th>
<th>Running Economy V̇O₂ max (ml.kg⁻¹.min⁻¹)</th>
<th>% V̇O₂ max</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (Male)</td>
<td>59.2</td>
<td>18.43</td>
<td>49.7</td>
<td>84.0</td>
<td>34.4</td>
<td>58.1</td>
</tr>
<tr>
<td>B (Male)</td>
<td>58.3</td>
<td>19.63</td>
<td>49.9</td>
<td>84.2</td>
<td>39.0</td>
<td>67.3</td>
</tr>
<tr>
<td>C (Female)</td>
<td>47.2</td>
<td>22.27</td>
<td>40.9</td>
<td>86.7</td>
<td>34.4</td>
<td>72.9</td>
</tr>
<tr>
<td>D (Female)</td>
<td>47.6</td>
<td>24.60</td>
<td>40.5</td>
<td>85.1</td>
<td>37.8</td>
<td>79.4</td>
</tr>
</tbody>
</table>

* Calculated from individual regression equation

Sjödin and Schéle (1982) reported a range of 14.4 ml.kg⁻¹.min⁻¹ in the oxygen consumption at 4.17 m.s⁻¹ for a group of long-distance runners, who also demonstrated a range of V̇O₂ max values and large variations in performance over 5km. In the present study the range of oxygen uptake at 3.13 m.s⁻¹ was 12 ml.kg⁻¹.min⁻¹ in the male subjects and 14.2 ml.kg⁻¹.min⁻¹ in the females.

While those men and women who recorded similar V̇O₂ max values were able to consume similar amounts of oxygen and utilise approximately 90% V̇O₂ max at 5km pace, differences in V̇O₂ max did not account fully for differences in running performance (Table III). Where individuals possessed similar V̇O₂ max values differences in running economy may have accounted for differences in performance. Partial correlational analysis (performance, V̇O₂ max and running economy at 3.13 m.s⁻¹) did not reveal any strong relationship between V̇O₂ max and running economy r = 0.10 (ns; men) r = 0.45 (p < 0.01; women) and r = 0.33 (p < 0.01; men and women).

Relative Exercise Intensity (%V̇O₂ max)

When running economy is expressed as relative exercise intensity (%V̇O₂ max), strong correlations with running performance are observed because this “value expresses both the effects of V̇O₂ max and running economy, which may both be separately related to performance” (Sjödin and Svedenhag, 1985). Costill and co-workers (1973) and Colguhoun (1984) have demonstrated a range of V̇O₂ max values at 4.17 m.s⁻¹ and performance over 5km. In the present study strong correlations were found between the %V̇O₂ max at 3.13 m.s⁻¹ and performance for the men (r = 0.85; p < 0.01) and women (r = 0.84; p < 0.01) respectively. These correlations were similar to those reported for V̇O₂ max and running performance.

The estimated relative exercise intensity during 5km performance was 67.0 ± 5.6% V̇O₂ max and 88.2 ± 5.1% V̇O₂ max for the men and women respectively (ns). These values are lower than the 93.6 ± 3.2% V̇O₂ max utilised over 5km by elite distance runners (Davies and Thompson, 1979) and the 92.1 ± 4.7% V̇O₂ max utilised by young male middle-distance runners (Colguhoun, 1984). The slightly lower %V̇O₂ max sustained by the subjects in the present study may reflect differences in both training and experience compared with the %V̇O₂ max sustained by the elite runners. The %V̇O₂ max values quoted above were not corrected for air resistance (Pugh, 1970). Recently Davies (1980) has estimated the extra energy cost of overcoming air resistance in outdoor track running to be 4% at middle-distance speeds.

The relationship between 5km running performance and V̇O₂ max could be described in the form of a linear regression equation for both the men and women. Thus for the male maximal oxygen uptake, V̇O₂ max, (y value; ml.kg⁻¹.min⁻¹) could be predicted from a 5km performance time (x value; min) using the equation:

\[ V̇O₂ max = 104.0 - 2.32 \times (5km \text{ time}) \]

with an estimated standard deviation of 3.3 ml.kg⁻¹.min⁻¹. The corresponding equation for the women in this study was:

\[ V̇O₂ max = 75.7 - 1.19 \times (5km \text{ time}) \]

with an estimated standard deviation of 2.9 ml.kg⁻¹.min⁻¹. The relationship between V̇O₂ max and 5km time shown in Fig. 1 was curvilinear over the full range of V̇O₂ max values. If the results are redrawn as a log-log plot (log_vo2 max or log5km time) then the linear relationship between V̇O₂ max and 5km time is described by the following equation:

\[ \log_vo2 max = 6.54 - 0.844 \log_5km \text{ time} \]

with an estimated standard deviation of 0.1. The correlation between V̇O₂ max and 5km time increases from \( r = -0.89 \) to \( r = -0.91 \) using a log-log plot.

**SUMMARY**

The correlation between 5km running performance and V̇O₂ max in active men and women was \( r = -0.89 \) (p < 0.01). The results of this study suggested that the relative running economy may discriminate between individuals possessing similar V̇O₂ max values in terms of 5km performance. The linear regression equations presented for both men and women in this study may be used to give an estimate of the maximal oxygen uptake (ml.kg⁻¹.min⁻¹) from a 5km performance run (min). The difference between the performance times recorded by the men and women in the present study is best explained by differences in their respective V̇O₂ max values.

**References**


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**BOOK REVIEW**

**Title:** COMMON SPORTS INJURIES IN YOUNGSTERS  
**Authors:** R. B. Birrer and D. B. Brecher  
**Publishers:** Medical Economic Books, New Jersey  
**Price £24.20 + £1.50 p & p 144 pages incl. Index Figs. and Tables ISBN 0-87489-420-4**

This paperback is written by Americans for Americans and as such appears comprehensive and useful for the intended readership.

It is a difficult book for a British reviewer to assess and its general application to those concerned with sports medicine in schoolchildren in this country seems limited. The text is liberally sprinkled with eponyms. A sentence on page 66 intrigued me:— “These include the drop-arm, apprehension, Yergason, Gilchrist, Ludington, Lippman, Booth and Marvel tests”. In over 34 years of close involvement with sports injuries to the adolescent I never heard of, let alone performed, any of these tests and I feel no guilt. My mind boggled over the precise meaning of “A poorly executed crossover step while cutting can sprain the lateral ligament of the planted leg” (page 112).

I recommend this book to North American readers mainly.

John Sparks