Running economy and distance running performance of highly trained athletes

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ABSTRACT

CONLEY, DOUGLAS L. and GARY S. KRAHENBUHL. Running Economy and distance running performance of highly trained athletes. Med. Sci. Sports Exercise. Vol. 12, No. 5, pp. 357-360, 1980. The purpose of the study was to determine the relationship between running economy and distance running performance in highly trained and experienced distance runners of comparable ability. Oxygen uptake (VO2) during steady-state and maximal aerobic power (VO2max) were measured during treadmill running using the open-circuit method. Distance running performance was determined in a nationally prominent 10 km race; all subjects (12 males) placed among the top 19 finishers. The subjects averaged 32.1 min on the 10 km run, 71.7 ml·kg⁻¹·min⁻¹ for VO2max, and 44.7, 50.3, and 55.9 ml·kg⁻¹·min⁻¹ for steady-state VO2 at three running paces (241, 268, and 295 m·min⁻¹). The relationship between VO2max and distance running performance was r = -0.12 (p = 0.35). The relationships between steady-state VO2 at 241, 268, and 295 m·min⁻¹ and 10 km time were r = 0.83, 0.82, and 0.79 (p<0.01), respectively. Within this elite cluster of finishers, 65.4% of the variation observed in race performance time on the 10 km run could be explained by variation in running economy. It was concluded that among highly trained and experienced runners of comparable ability and similar VO2 max, running economy accounts for a large and significant amount of the variation observed in performance on a 10 km race.

DISTANCE RUNNING, OXYGEN UPTAKE, RUNNING ECONOMY

Successful performance in competitive distance running has been attributed primarily to the athlete's ability to consume oxygen maximally (3,6,15). A variation of this view is that a high VO2max may be a prerequisite for success in distance running, but that among runners possessing this essential attribute, the fractional utilization of VO2max, muscle fiber composition, peak muscle and blood lactate accumulation, and running economy may be important (4,10,11,12,14,16).

Running economy is considered to be the steady-state oxygen consumption (ml·kg⁻¹·min⁻¹) for a standardized running speed (10). Running economy varies considerably among trained runners (1,7,9,10,13,14). Costill (6) suggests that intraindividual variations in running economy at standardized speeds are "random" and of little value in differentiating distance running ability. Correlations between running economy and performance in running events have ranged from r = 0.36 (23 experienced runners in the marathon (12) to r = 0.60 (18 experienced distance runners on a 9.7 km race (10)).

Previous reports on the relationship between running economy and distance running performance have been peripheral to other purposes in experiments and have been based on populations exhibiting heterogeneity on both VO2max and running ability. The purpose of the present study was to determine the relationship between running economy and distance running performance in highly trained distance runners more homogeneous in ability.

METHODS

The subjects for the study were 12 highly trained and experienced male runners who placed among the top 19 in a nationally prominent 10 km race. The laboratory data were collected during the third to sixth days following the competitive run. Maximal oxygen uptake and skinfolds were measured on the first of two laboratory visits. Each subject wore the same shoes and clothing for the laboratory testing as he had worn during the 10 km run. Body weights included the weight of this clothing since it contributed to the running workload. Shoes were removed for height measurement. Skinfolds were measured at six sites (triceps, subscapular, suprailiac, umbilical, pectoral, and anterior mid-thigh) using a Harpenden caliper.

Maximal oxygen uptake was determined using the open-circuit method, treadmill running, and a continuous protocol. Treadmill speed was kept at 214 m·min⁻¹ for all stages. Stage one was a 4-min warm-up at level grade. At the close of the fourth and each subsequent minute until the subject reached exhaustion, grade was increased 2/4%. The criteria described by McMiken and Daniels (13) were used in determining the subject's VO2max.

All three submaximal tests were conducted on the subject's second visit to the laboratory. The laboratory was air-conditioned and kept at 18°C for all runs. The procedure was identical to that utilized by McMiken and Daniels (13). After a warm-up of 5 min at 214 m·min⁻¹, the subjects completed runs, 6 min in duration, at 241 m·min⁻¹, 268 m·min⁻¹, and 295 m·min⁻¹ with 3 min rest between tests. Serial, 1-min collections were made over the last 3 min of each 6-min run. The values obtained for individual
subjects indicated that they were all in steady-state for the three collections at each speed. The mean of the three collections was taken as the aerobic requirement. No respiratory exchange ratios exceeded 1.00. Treadmill belt speed was calibrated prior to each submaximal test and rechecked during the first minutes of the run for every subject. This procedure resulted in an accuracy of ±0.5 treadmill belt revolutions per minute.

Expired gas samples from both the maximal and submaximal tests were collected in meteorological balloons through a breathing valve and collection system described by Daniels (8). Gas samples were passed through a drying tube and analyzed for CO₂ and O₂ with the Beckman LB-2 and 4-digit OM-11, respectively. The gas analyzers were calibrated at the beginning and end of each test, using standards previously analyzed with a Gallenkamp-Lloyd volumetric analyzer. Drift between calibrations was, in each case, within the published instrument error in overall accuracy; therefore, no corrections in the data were indicated. Expired gas volumes were determined with a Parkinson-Cowen, CD-4 gas meter.

RESULTS AND DISCUSSION

The subjects in this study exhibited a tight cluster of excellent 10 km run times (Table 1). The ranges for VO₂max and relative fat were also narrow and the mean values were what would be expected for the caliber of runner studied.

When comparing the mean physical characteristics in this study to the mean values reported in studies by McMiken and Daniels (13), Daniels et al. (9), and Costill, Thomason, and Roberts (6) involving groups of 8, 10, and 16 highly trained male distance runners, marked similarities are found. The range in mean heights varies by 9 cm (174-183). Mean weights vary by only 3 kg (63.1-66.1). Finally, means for VO₂max are separated by 7.6 ml·kg⁻¹·min⁻¹ (66.1-73.7).

The relationship between VO₂max and performance in the 10 km run was r = 0.12, which was not significantly (p = 0.35) different from zero, due to the homogeneity of the group, and was much lower than the relationships reported from earlier studies (Table 2). Although the test race distances were similar to a number of previous studies (3,6,10,11), the current subject group was much more homogeneous on both performance and VO₂max than were the group members from these earlier investigations.

It cannot be argued from these data that VO₂max is unimportant, for all the subjects exhibited high values. The current data, however, suggest that a high VO₂max helped each subject gain membership in this elite performance cluster, but it did not discriminate success on a 10 km race within this group.

The submaximal aerobic requirements depicted in Figure 1 are very similar to those reported in earlier studies (6,9). At submaximal speeds of 241 and 268 m·min⁻¹, Daniels et al. (9) recorded mean VO₂’s of 44.6 and 50.5 ml·kg⁻¹·min⁻¹ for 10 highly trained male distance runners. Costill, Thomason, and Roberts (6) reported mean VO₂’s of 45.6, 51.7, and 59.0 ml·kg⁻¹·min⁻¹, for the respective speeds of 241, 268, and 295 m·min⁻¹, for 16 highly trained male distance runners. The mean aerobic requirements for the 12

**TABLE 1. Physical characteristics of the subjects.**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age (Years)</th>
<th>Years of Training</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Skinfold Sum* (mm)</th>
<th>VO₂max (ml·kg⁻¹·min⁻¹)</th>
<th>10 km Run Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>25</td>
<td>9</td>
<td>183</td>
<td>63.3</td>
<td>34.8</td>
<td>77.74</td>
<td>30.52</td>
</tr>
<tr>
<td>B</td>
<td>28</td>
<td>14</td>
<td>178</td>
<td>60.6</td>
<td>26.0</td>
<td>67.74</td>
<td>30.98</td>
</tr>
<tr>
<td>C</td>
<td>28</td>
<td>14</td>
<td>196</td>
<td>78.1</td>
<td>31.8</td>
<td>70.55</td>
<td>31.15</td>
</tr>
<tr>
<td>D</td>
<td>24</td>
<td>10</td>
<td>185</td>
<td>70.4</td>
<td>35.3</td>
<td>70.30</td>
<td>31.28</td>
</tr>
<tr>
<td>E</td>
<td>30</td>
<td>15</td>
<td>175</td>
<td>62.0</td>
<td>33.5</td>
<td>71.95</td>
<td>31.75</td>
</tr>
<tr>
<td>F</td>
<td>18</td>
<td>05</td>
<td>175</td>
<td>67.2</td>
<td>30.5</td>
<td>73.95</td>
<td>31.95</td>
</tr>
<tr>
<td>G</td>
<td>25</td>
<td>12</td>
<td>180</td>
<td>68.6</td>
<td>28.1</td>
<td>70.55</td>
<td>32.57</td>
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<tr>
<td>H</td>
<td>19</td>
<td>06</td>
<td>173</td>
<td>71.7</td>
<td>29.6</td>
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<td>32.57</td>
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<tr>
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<td>68.6</td>
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<td>71.79</td>
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</tr>
<tr>
<td>L</td>
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<td>08</td>
<td>178</td>
<td>74.9</td>
<td>29.2</td>
<td>73.72</td>
<td>33.55</td>
</tr>
</tbody>
</table>

*Tricep, subscapular, suprailiac, umbilical, pectoral, and anterior mid-thigh

**TABLE 2. Relationship of VO₂max to running performance in this and previous studies using similar distances.**

<table>
<thead>
<tr>
<th>Study</th>
<th>Subjects</th>
<th>VO₂max Range</th>
<th>Test Race Distance</th>
<th>Performance Range (min)</th>
<th>Relationship between VO₂max and Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costill (3)</td>
<td>Collegiate Cross Country (n=17)</td>
<td>50 - 67</td>
<td>4.7 mi</td>
<td>24.3 - 33.3</td>
<td>-0.82</td>
</tr>
<tr>
<td>Costill et al. (6)</td>
<td>Trained Distance Runners (n=16)</td>
<td>55 - 82</td>
<td>10.0 mi</td>
<td>48.3 - 68.2</td>
<td>-0.91</td>
</tr>
<tr>
<td>Foster et al. (11)</td>
<td>Well-Trained Runners (n=26)</td>
<td>49 - 73</td>
<td>6.0 mi</td>
<td>29.9 - 46.6</td>
<td>-0.88</td>
</tr>
<tr>
<td>Farrell et al. (10)</td>
<td>Experienced Runners (n=18)</td>
<td>46 - 74</td>
<td>15.0 km</td>
<td>45.9 - 73.6</td>
<td>-0.89</td>
</tr>
<tr>
<td>Present Investigation</td>
<td>Highly-Trained and Experienced Runners (n=12)</td>
<td>67 - 77</td>
<td>10.0 km</td>
<td>30.5 - 33.6</td>
<td>-0.86</td>
</tr>
</tbody>
</table>
Figure 1—The relationship between steady-state oxygen uptake and treadmill running pace in 12 highly-trained and experienced male distance runners.

Subjects in this study were 44.7, 50.3, and 55.9 ml·kg⁻¹·min⁻¹ for the same submaximal speeds.

The relationship between oxygen uptake and running pace is depicted in Figure 1. The slope of the group regression line (+0.209) is very similar to the ones reported by Costill and Fox (5) (+0.204), Daniels et al. (9) (+0.211), and Bransford and Howley (2) (+0.204 and +0.203). The individual data points showed close adherence to their respective linear regression lines. Subject correlation coefficients calculated from the three data points (Vo₂ at 241, 268, 295 m·min⁻¹) ranged from 0.995 to 0.999 with a mean of 0.998. Standard errors of the estimate ranged from 0.008 to 0.014 with a mean of 0.045 ml·kg⁻¹·min⁻¹. These data support the concept that the relationship between the aerobic requirements of running and the running pace between 241 and 295 m·min⁻¹ can be adequately described by a linear regression equation.

The importance of running economy among runners of comparable ability is suggested in Figure 2. The relationship between performance on a 10 km race and the aerobic requirements of three standardized running paces (241, 268, and 295 m·min⁻¹) is shown. The coefficients range from r = 0.79 to r = 0.83. All are statistically significant at or beyond the 99% level of confidence. By averaging r² for the three paces, it may be stated that within this elite cluster of finishers 65.4% of the variation observed in race performance on the 10 km race can be explained by variation in running economy.

Costill et al. (6) have shown that the fractional utilization of aerobic capacity (% Vo₂max) at submaximal speeds is highly related to running performance among runners with a wide range of abilities and Vo₂max. In the current study, the relationships between running performance and percent of Vo₂max at submaximal speeds were nearly iden-

Figure 2—The relationship between 10 km race time (y-axis) and steady-state oxygen uptake at 241 m·min⁻¹ (x-axis; top), 268 m·min⁻¹ (x-axis; middle), and 295 m·min⁻¹ (x-axis; bottom) in 12 highly-trained and experienced male distance runners.
tical to the relationships between performance and \( \text{VO}_2 \). Percent \( \text{VO}_{2\text{max}} \) is derived from \( \text{VO}_{2\text{max}} \) and \( \text{VO}_{2\text{submax}} \), therefore, in a group homogeneous in \( \text{VO}_{2\text{max}} \) it is not surprising that percent of \( \text{VO}_{2\text{max}} \) accounted for no more variation in performance than did \( \text{VO}_{2\text{submax}} \) alone.

Once a minimal threshold of work is passed, lactic acid accumulation is a function of percent of \( \text{VO}_{2\text{max}} \) (2,10). Farrell et al. (10) recently demonstrated that the onset of plasma lactate accumulation is closely related to the pace a runner is able to maintain for long races. It seems reasonable to assume, albeit speculation, that running economy is important to distance running because the relative intensity (percent of \( \text{VO}_{2\text{max}} \)) of a given pace would be lower for an economical runner than it would be for a less economical runner with a comparable \( \text{VO}_{2\text{max}} \). The variation in performance not accounted for by the economy of the subjects may be due to interindividual differences in muscle fiber composition, anaerobic threshold, and peak muscle and blood lactate tolerance.

Two questions which are typically raised when comparing treadmill with track data are: (1) does the lack of wind resistance on the treadmill nullify the implications suggested for overland running, and (2) do treadmill determinations of the aerobic requirements of running at 85% of \( \text{VO}_{2\text{max}} \) (the highest relative workload observed at 295 m·min\(^{-1}\)) seriously underestimate the energy requirement during heavy exercise? Previous authors (2,6,13) have provided data and discussion which suggest that for the paces and relative intensities in the present study, error from these two sources may be regarded as inconsequential.

In summary, the most important finding of this study is that among highly trained and experienced runners of comparable ability and similar \( \text{VO}_{2\text{max}} \) running economy accounts for a large and significant amount of the variation observed in performance in a 10 km race. This conclusion does not argue against the importance of \( \text{VO}_{2\text{max}} \), for all subjects exhibited high values. Rather, it appears that the importance of economy may be expressed only when performers are of comparable ability with similar maximal aerobic capacities.

**REFERENCES**