Physiologic Comparison of Adolescent Female and Male Cross-Country Runners

Lee N. Cunningham

To compare the physiologic differences between adolescent male and female cross-country runners, 12 male and 12 female high school nonelite distance runners who had competed successfully at the All State 5-km championship cross-country meet were tested in the laboratory. Data were analyzed in relation to maximal oxygen consumption (VO$_2$max), ventilatory threshold (VT), and running economy (RE). Male runners were taller, heavier, had less body fat, and ran faster by 2 minutes and 18 seconds than female runners. Running economy was similar between gender. VO$_2$ at a 215 m•min$^{-1}$ pace was 46.7 ml•kg$^{-1}$•min$^{-1}$ for male runners and 47.8 ml•kg$^{-1}$•min$^{-1}$ for female runners. At the VT, males demonstrated a higher VO$_2$ and treadmill velocity than females. Heart rate, percent HR max, and percent VO$_2$max at the VT were not different between gender. Males demonstrated a higher VO$_2$max of 74.6 versus 66.1 ml•kg$^{-1}$•min$^{-1}$ than female runners. The fractional utilization of VO$_2$ at race pace was not different between males (90%) and females (91%). In conclusion, the primary physiologic determinant for performance differences between nonelite, competitive male and female adolescent distance runners is associated with VO$_2$max.

A perusal of the world records for sprint, middle-, and long-distance running reveals that male runners outperform female runners from the 100-meter to the marathon (20). Exercise scientists have attempted to explain this observation particularly for the middle- and long-distance events by profiling the physiology of elite male and female runners (7, 13, 23). The primary findings were that elite male runners demonstrated a higher VO$_2$max, higher hemoglobin content, and lower percent body fat when compared to elite female runners.

Several studies have focused directly upon the male/female comparison (1, 6, 12, 22). Studies by Pate et al. (12) and Wells and colleagues (22) were completed with runners closely matched for VO$_2$max and/or performance. Pate and colleagues reported similar physiologic profiles for VO$_2$max and submaximal VO$_2$ between male and female runners who were matched on performance. Wells and co-workers studied a group of well-trained male and female marathon runners. The female runners, who completed the marathon faster despite similar VO$_2$max values, demonstrated the ability to utilize a larger fraction of their aerobic power.

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during the actual competition. Daniels et al. concluded from a study of highly trained male and female runners that variances in performance were mainly attributable to VO₂ max differences since the VO₂ at submaximal speeds were equal (6). Bransford and Howley suggested that male collegiate runners used less VO₂ to run at a similar pace than female collegiate runners (1). However, others have reported no statistically significant differences between gender (6, 8, 12) in regards to the energy cost of running at a similar pace.

Little comparative physiologic data for high school runners was available from the literature. Therefore, this study compared performances of well-trained adolescent male and female cross-country runners in relation to the three basic physiologic variables known to influence success in distance running: (a) maximal oxygen consumption (VO₂ max), (b) the percent of VO₂ max that can be utilized for a given distance and the ventilatory threshold, and (c) running economy (3, 11, 16, 18). The goal was to assess which of these physiologic determinants for running success may be associated with gender differences in performance between high school nonelite, but highly competitive, well-trained male and female distance runners.

**Methods**

Twelve female and 12 male cross-country runners were tested in the laboratory within 2 weeks of the Massachusetts All State 5-km cross-country championship meet. Coaches of six successful cross-country running programs involving four female and two male high school teams were given the opportunity to test their seven best performers. All of these teams were divisional winners at the district level and had qualified for the All State Meet. The female runners placed from 5th to 78th while the male runners finished from 4th to 145th. It is noteworthy that one of the female teams included in this study won the All State Meet and one of the male teams placed 2nd in the boys’ section.

The mean run time difference between gender was 2 minutes and 18 seconds. This compares favorably to the run time difference for the top 10 male and female finishers of 2 minutes and 29 seconds. This suggests that the runners included in the present study were representative of the performance differences generally observed between well-trained male and female adolescent distance runners. The training distance over the season was approximately 63 km·week⁻¹ based upon coaches’ estimates, and these runners had been competing for 4.8 years. Informed consents were signed by all runners and their parents. The protocol was approved by the Human Studies Committee at Fitchburg State College.

Body composition was evaluated by using the Jackson, Pollock, and Ward equation for females (10) and the Jackson-Pollock equation for males (9). Skinfold measurements were taken at three sites for female runners (10) and seven sites for male runners (9). All measurements were taken from the right side of the body using a Harpenden skinfold caliper. Two independent measurements were taken at each site. If the second measurement was not within 5% of the first, additional skinfolds were taken until the criterion of 5% was met. Sinning and Wilson (15) and Sinning et al. (14) have cross-validated use of these equations for body composition analysis with female and male athletes, and Thorland and co-workers (19) reported that the quadratic equations of Jackson et al. (10) and Jackson and Pollock (9) were appropriate for estimating body density in adolescent athletes.
Exercise testing was performed in the cardiovascular laboratory at Burbank Hospital, Fitchburg, Massachusetts. The treadmill testing was completed in a single session. Each runner performed a continuous submaximal run on a motor driven treadmill (Model Q55, Quinton Instruments, Seattle, WA) at a pace of 160 (6 mph), 188 (7 mph), 215 (8 mph), and 241 (9 mph) m•min⁻¹ for 4 minutes each. At the conclusion of the final 4 minutes of the submaximal run, the treadmill slope was increased by a 2.5% grade every minute until a maximal effort was achieved as determined by a respiratory exchange ratio (RER) greater than 1.0, a plateau of VO₂max of less than 250 ml•min⁻¹ with increased treadmill slope, and an HR max within 10% of predicted, adjusted for age by the equation HR max = 210 – (.65 × age). If two of the three criteria were met, the test was considered a maximal effort. The two highest 30-second VO₂ measures were averaged for VO₂max determination.

Metabolic and ventilatory data were obtained every 30 seconds by using a Metabolic Measurement Cart (SensorMedics, Schiller Park, IL). Heart rates were obtained from a single-lead ECG (CM5) by using a Quinton Stress Test Monitor (Model Q3000, Quinton Instruments, Seattle, WA). Expired volume was calibrated with a 1- and 3-liter syringe, and the gas analyzers were calibrated with known gas concentrations. The ventilatory threshold (VT) was determined by using the breakpoint from linearity of VE/VO₂ while the VE/VCO₂ remained unchanged plotted against VO₂ (21).

Running economy (RE) was defined as the VO₂ required per unit of body weight to perform a treadmill run at 215 m•min⁻¹ pace. The rating of perceived exertion was obtained by using a psychophysical scale developed by Borg and Linderholm (2). The runners rated their feelings of exertion at the end of each stage of treadmill running up to maximal effort. Any derived variables such as velocity at VT (vVT), velocity at VO₂max (vVO₂max), and VO₂ associated with the All State Meet running speed to determine fractional utilization at race pace were obtained from the linear regression of each runner’s submaximal VO₂/running velocity data. Oxygen consumption at RE pace, VT, and maximal exercise was the primary marker used to extract physiologic data (i.e., HR, RPE, and velocity) as shown in Tables 2, 3, and 4. These data were based upon the linear regression of VO₂ velocity during the treadmill test. The data were analyzed for means and standard deviations. A student t test for independent means was used to compare differences for various criterion measures between male and female runners. Statistical significance was defined as p<0.05.

Results

Characteristics of the subjects, anthropometric data, and performance variables are summarized in Table 1. Runners were of similar age but males were taller, heavier, and showed a lower percent body fat than female runners. There were no differences in training experience between gender (p>0.05). However, males ran significantly more distance over the training season from September to mid-November than did females (p>0.05). The distance run in training was reported by the coaches. Males ran the 5-km State Meet on average 2:18 minutes faster than female runners. Fractional utilization of VO₂max at race pace was not significantly different between gender (p>0.05).

Running economy was similar between these male and female runners.
Table 1
Anthropometric and Performance Characteristics of the Subjects

<table>
<thead>
<tr>
<th></th>
<th>Males (N=12)</th>
<th>Females (N=12)</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>16.6 ± 1.0</td>
<td>16.2 ± 0.9</td>
<td>1.05</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>62.7 ± 6.0</td>
<td>52.0 ± 7.3</td>
<td>3.76*</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>177.8 ± 4.1</td>
<td>164.0 ± 7.6</td>
<td>5.38*</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>5.3 ± 1.3</td>
<td>12.4 ± 3.6</td>
<td>6.15*</td>
</tr>
<tr>
<td>State meet time (Min:sec)</td>
<td>17:27 ± 1:21</td>
<td>19:45 ± 1:06</td>
<td>7.71*</td>
</tr>
<tr>
<td>Estimated fractional util.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>of VO₂ at race pace (%)</td>
<td>90 ± 3.0</td>
<td>91 ± 7.2</td>
<td>0.50</td>
</tr>
<tr>
<td>Experience (yrs)</td>
<td>4.8 ± 1.2</td>
<td>4.8 ± 1.0</td>
<td>0.18</td>
</tr>
<tr>
<td>Distance-week⁻¹ (km)</td>
<td>68.9 ± 5.2</td>
<td>59.1 ± 6.8</td>
<td>3.62*</td>
</tr>
</tbody>
</table>

Values are mean ± SD. For df = 22, t = 2.07 for statistical significance at 0.05. *p<.05.

Table 2
Selected Variables for Running Economy (7:30 min/mile pace)

<table>
<thead>
<tr>
<th></th>
<th>Males (N=12)</th>
<th>Females (N=12)</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO₂ (ml·kg⁻¹·min⁻¹)</td>
<td>46.7 ± 3.7</td>
<td>47.8 ± 3.3</td>
<td>0.65</td>
</tr>
<tr>
<td>VO₂max (%)</td>
<td>62.6 ± 4.7</td>
<td>73.2 ± 8.3</td>
<td>2.96*</td>
</tr>
<tr>
<td>Heart rate (b·min⁻¹)</td>
<td>161 ± 11.4</td>
<td>178 ± 14.5</td>
<td>3.02*</td>
</tr>
<tr>
<td>Heart rate max (%)</td>
<td>82 ± 4.5</td>
<td>88 ± 6.0</td>
<td>2.67*</td>
</tr>
<tr>
<td>RPE (Borg units)</td>
<td>11.2 ± 1.6</td>
<td>12.2 ± 1.4</td>
<td>0.95</td>
</tr>
<tr>
<td>RER</td>
<td>0.95 ± 0.03</td>
<td>0.92 ± 0.05</td>
<td>1.91</td>
</tr>
<tr>
<td>Vₑ (L·min⁻¹)</td>
<td>69 ± 6.3</td>
<td>63 ± 8.4</td>
<td>2.00</td>
</tr>
</tbody>
</table>

Values are mean ± SD. For df = 22, t = 2.07 for statistical significance at 0.05. *p<.05.

(Table 2). However, the physiology to accomplish running at a 215 m·min⁻¹ pace did differ. Female runners used a larger percent VO₂max at a 215 m·min⁻¹ pace (73 and 64%) and demonstrated a higher heart rate (178 to 161 b·min⁻¹) and higher percent max heart rate (88 to 82%) than male runners (p<0.05). Minute ventilation; RER, and RPE did not differ between gender (p>0.05).

Table 3 shows the ventilatory threshold data. Male runners demonstrated
a higher VO₂, Vₑ, and vVT than female runners (p<0.05). However, percent VO₂max at VT, HR, percent HR max, RPE, and RER were not different between the sexes (p>0.05). A fairly strong correlation between VT-VO₂ and VO₂max of r=0.716 was calculated. At maximal effort, males showed a higher VO₂max, RER, Vₑ, and vVO₂max, as shown in Table 4 (p<0.05). Maximal HR was not significantly different between groups (p>0.05). Figure 1 depicts the VO₂/running velocity relationship. There were no significant differences between gender when regression analysis was performed for either the slope or the intercept (p>0.05).
Figure 1 — Oxygen uptake at increasing running velocities in male and female runners. The slope and intercept were not significantly different between gender (p>0.05). These data show a similar running economy between the sexes. The difference in performance is reflected in the higher VO$_2$max. The velocity at VO$_2$max, which is determined by dropping a vertical line from max values to the x-axis, is significantly different between female and male runners (267 m·min$^{-1}$ and 320 m·min$^{-1}$, respectively).

Discussion

The major finding of this study was that when performance times differ, VO$_2$max was the primary determinant associated with actual running time between male and female high school distance runners. This is in agreement with Daniels et al. (6), who found that performance differences between highly trained adult male and female runners were mainly attributable to differences in VO$_2$max.

Factors that may explain differences in VO$_2$max between males and females have been suggested to be related to oxygen transport, body composition, and training (7). In the present study, the training history between gender was similar in terms of years of running experience. Although the total training distance run·week$^{-1}$ was significantly greater for male runners (p<0.05), both male and female runners were well trained coming from successful high school distance running programs.

Body composition is a critical variable for explaining gender difference in running performance. Drinkwater (7) has proposed that when the contribution of body fat to sex differences in VO$_2$max is removed, the remaining differences
must represent either the actual difference in conditioning or a sex-linked difference in the capacity to transport and utilize oxygen. Reviewing data from studies of men and women tested in the same laboratory for Alpine and Nordic skiing, distance running, tennis, volleyball, and orienteering, when VO\textsubscript{2max} was expressed as L \textbullet min\textsuperscript{-1}, ml \textbullet kg\textsuperscript{-1} \textbullet min\textsuperscript{-1}, and ml \textbullet kgLBW\textsuperscript{-1} \textbullet min\textsuperscript{-1}, Drinkwater reported that the differences between the sexes averaged 51.5, 18.6, and 9%, respectively (7).

Sparling found gender differences of 56, 28, and 15% for VO\textsubscript{2max} when expressed similarly based upon a meta-analysis of 13 similar studies (13). However, using data in which the training history was similar, he found percent differences of 56, 18, and 5 for VO\textsubscript{2max} expressed as L \textbullet min\textsuperscript{-1}, ml \textbullet kg\textsuperscript{-1} \textbullet min\textsuperscript{-1}, and ml \textbullet kgLBW\textsuperscript{-1} \textbullet min\textsuperscript{-1}, respectively, between the sexes (17).

The present study showed differences that were much tighter for VO\textsubscript{2max} expressed as L \textbullet min\textsuperscript{-1}, ml \textbullet kg\textsuperscript{-1} \textbullet min\textsuperscript{-1}, and ml \textbullet kgLBW\textsuperscript{-1} \textbullet min\textsuperscript{-1} (4, 12, and 5%, respectively). Cureton suggests that a difference of 5% in VO\textsubscript{2} expressed as ml \textbullet kgLBW\textsuperscript{-1} \textbullet min\textsuperscript{-1} can be attributed to inherent biological differences between the sexes (4). In the present study, where well-trained, experienced runners were tested and corrections were made for body fat, the differences in VO\textsubscript{2max} are suggested to be sex linked. This interpretation must be viewed with caution since body composition was estimated from skinfold equations. How much of the remaining differences can be attributed to the lower hemoglobin concentration of the female, her smaller muscle-mass-to-body-weight ratio, or the smaller components in her oxygen transport system needs clarification.

Running economy did not differ between the sexes. This is in agreement with previous reports (6, 8, 12). In contrast, Bransford and Howley demonstrated that male collegiate runners are more economical than female runners of a similar age (1). The present study suggests that when running performance and VO\textsubscript{2max} are heterogeneous between gender, RE will be similar. This is in agreement with Daniels et al. (6). Some combination of running ability, biomechanics, anthropometric factors, elastic component of muscle, age, training, and muscle fiber types interact to determine VO\textsubscript{2} at a submaximal running speed (5).

Although the caloric cost of running a similar pace relative to body weight was identical between gender, the physiology to accomplish that task was different. A 215 m \textbullet min\textsuperscript{-1} pace reflected a greater intensity of exercise for the female runners since a larger percent of VO\textsubscript{2max}, higher heart rate, and greater percent of HR max were utilized. Further, the idea of correcting for body composition may be a moot question since running demands moving body weight.

The ventilatory threshold and lactate threshold have been suggested to be excellent predictors of running performance. In the present study, a significant difference was found between gender for VTVO\textsubscript{2} and vVT. This finding must be interpreted with caution since the VO\textsubscript{2} at the VT was strongly related with VO\textsubscript{2max}, $r$=0.714. Approximately 50% of the VTVO\textsubscript{2} is accounted for by VO\textsubscript{2max}. Further, the percent of VTVO\textsubscript{2} (78 and 79% between male and female runners, respectively) and the fractional utilization of VO\textsubscript{2} estimated to run a competitive meet (90 and 91% for male and female runners, respectively) were similar between gender. These data suggest that the estimated relative VT and the fractional utilization of VO\textsubscript{2max} to run a competitive meet are not linked to performance differences between male and female adolescent distance runners.
In conclusion, the primary physiologic variable for performance differences between nonelite but well-trained competitive male and female adolescent distance runners is related to \( \text{VO}_{2}\text{max} \). Additional studies with this age group to test for a “true” biologic difference between the sexes are required where training distance is equal and a laboratory method to more directly measure body composition is utilized. Other considerations include muscular power (11) and certain hematologic and cardiovascular variables that may identify specific factors of the oxygen transport system to explain gender difference in adolescent runners.

References


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