Anaerobic Work Capacity’s Contribution to 5-km-Race Performance in Female Runners

Cory W. Baumann, Jeffrey C. Rupp, Christopher P. Ingalls, and J. Andrew Doyle

Purpose: The purpose of this study was to examine the relationship between anaerobic characteristics and 5-km-race performance in trained female cross-country runners (N = 13). Methods: The runners performed 50-m sprints and a 5-km time trial on an outdoor 400-m track and maximal anaerobic (MART) and aerobic running tests on a motorized treadmill. Anaerobic characteristics were determined by the mean velocity of the 50-m sprint \(v_{50m}\) and the peak velocity in the MART \(v_{MART}\). The aerobic characteristics were obtained during the aerobic treadmill test and included maximal oxygen uptake (VO\(_{2\text{max}}\)), running economy, and ventilatory threshold (VT). Results: Both the \(v_{MART}\) \((r = .69, P < .01)\) and VO\(_{2\text{max}}\) \((r = .80, P < .01)\) correlated with the mean velocity of the 5-km \(v_{5km}\). A multiple-linear-regression analysis revealed that the combination of VO\(_{2\text{max}}\), \(v_{MART}\), and VT explained 81% \((R^2 = .81, P < .001)\) of the variation seen in the \(v_{5km}\). The \(v_{MART}\) accounted for 31% of the total shared variance, while the combination of VO\(_{2\text{max}}\) and VT explained the remaining 50%. Conclusions: These results suggest that among trained female runners who are relatively matched, anaerobic energy production can effectively discriminate the \(v_{5km}\) and explain a significant amount of the variation seen in 5-km-race performance.

Keywords: running success, sports physiology, maximal oxygen uptake, training
performance in runners. The anaerobic-energy contributions of the MART have been reported to range from 64% to 72% and 70% to 80%. Therefore, the purpose of this study was to examine the relationship between anaerobic characteristics (identified by the MART and 50-m sprint) and 5-km-race performance in trained female cross-country runners.

Methods

Participants
Thirteen NCAA Division I female cross-country runners participated in this study. Eleven were currently competing at the college level, and the other 2 were runners no more than 3 years out of college. All participants were training for at least 2 months before the study and were involved in college and/or open races. Table 1 shows the participants’ physical characteristics and training backgrounds. Participants completed a medical-history questionnaire and an informed-consent form and were free of any medical limitations. All procedures were approved by the Georgia State University Institutional Review Board for the Protection of Human Subjects.

Experimental Design
The participants were required to visit the laboratory on 2 separate occasions followed by a meeting at an outdoor running track. The first laboratory visit familiarized them with the equipment and testing protocols. On the second laboratory visit participants completed all laboratory measures, which included body composition and 2 maximal treadmill tests. For those competing in college, laboratory testing began at least 3 days after their last cross-country race of the season; this was to ensure that they received adequate recovery after completing their last race. No more than 6 days after the second laboratory visit, participants reported to an outdoor track to assess 50-m-sprint velocity and 5-km-race performance. The investigators provided verbal motivation during each test. Throughout the duration of testing, participants were instructed to maintain their regular physical activity patterns.

All participants were asked to not eat during the 4 hours immediately before testing and refrain from performing strenuous exercise the day before and the day of testing. Before testing, height, body mass, and body composition were recorded. Body composition was determined using dual-energy X-ray absorptiometry (DEXA, Lunar Prodigy, General Electric, Madison, WI). After the DEXA scan, 2 maximal exercise tests were undertaken on a motorized treadmill (T-2100, GE Medical Systems, Information Technologies, Milwaukee, WI). Participants first performed a maximal aerobic-power test to identify VO2max, RE, and VT. On completion of the first treadmill test they were given a 30-minute recovery period before the second treadmill test, the MART. To note, this recovery period is 10 minutes longer than used in similar studies that allowed a 20-minute recovery.

Fifty-meter-sprint velocity and 5-km-race performance were tested on an outdoor 400-m track. Participants performed similar warm-ups of 30 minutes followed by 3 maximal 50-m sprints and a 5-km time trial. Weather conditions were nearly optimal, sunny to partly cloudy with an air temperature of 12°C and a slight breeze.

Maximal Aerobic-Power Test
VO2max, RE, and VT were obtained during the maximal aerobic-power test. Participants were connected to a metabolic measurement cart (Parvomedics TrueMax 2400, Salt Lake City, UT), and samples of expired gas were analyzed for oxygen consumption and carbon dioxide production. The metabolic cart was calibrated before every test. Heart rate was measured using a Polar monitor (Polar T31, Lake Access, NY). The test protocol began at a level grade with a warm-up walk at 1.33 m/s for 3 minutes and progressed incrementally to running at 2.67, 3.14, 3.56, and 4.03 m/s, each for 3 minutes except at 3.56 m/s. At that velocity, RE was determined, and participants ran at 3.56 m/s until a steady state in VO2 was achieved. Steady state was defined as a change in VO2 not exceeding ±2.5 mL · kg⁻¹ · min⁻¹ in any 2 consecutive minutes; the mean VO2 of those 2 minutes was used to quantify the participants’ RE. After the participants completed the stage at 4.03 m/s, velocity was increased again by 0.22-m/s increments each minute until exhaustion. This testing protocol follows that of Tharp et al. VT was determined using the computerized V-slope method and expressed as a percentage of VO2max. VO2max was taken as the highest mean of 2 consecutive 15-s VO2 measurements (mL · kg⁻¹ · min⁻¹).

Maximal Anaerobic-Power Test
An intermittent high-intensity treadmill test was used to estimate anaerobic work capacity. The MART consisted of series of 20-second runs on the treadmill with a 100-second recovery between runs. An acceleration phase was included in the 100-second recovery to allow the treadmill to reach the target velocity. The first run was performed at the velocity of 3.31 m/s, which increased by 0.36 m/s each consecutive 20-second run until exhaustion. The treadmill inclination remained at a constant 9%. Exhaustion in the MART was determined as the time

### Table 1 Descriptive Characteristics of the Runners (N = 13)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
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<tbody>
<tr>
<td>Age (y)</td>
<td>20.5 ± 2.1</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>163.3 ± 6.0</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>58.7 ± 5.7</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>24.2 ± 4.3</td>
</tr>
<tr>
<td>Running experience (y)</td>
<td>7.1 ± 2.3</td>
</tr>
<tr>
<td>Training (km/wk)</td>
<td>60.0 ± 12.1</td>
</tr>
</tbody>
</table>
when the participant could no longer run at the speed of the treadmill. Peak velocity in the MART (v_{MART}) was determined from the exhaustion time of the following faster run so that each additional 2 seconds after 10 seconds of running increased the v_{MART} by 1/6 of the velocity increase between runs.12

**Maximal 50-m-Sprint Test**

Fifty-meter sprints were performed to assess anaerobic power. Participants were informed to sprint as quickly as possible with a 20-m running start leading into the 50-m sprint. Participants received 5 to 8 minutes rest between trials to ensure full recovery. Total elapsed time was measured to the nearest 0.1 second for each test with an electronic stopwatch by 2 investigators independently. The investigators’ times for each trial were averaged. The fastest average time out of the 3 trials was used for data analysis and expressed as a mean velocity (v_{50m}).

**Five-Kilometer Time Trial**

After a 5- to 10-min recovery participants competed against one another in a 5-km time trial in order to simulate a competitive race. They were instructed to run as fast as possible using their normal pacing strategies. Elapsed times were read aloud and recorded each 400 m. For data analysis, 5-km-race performance was expressed as a mean velocity (v_{5km}).

**Statistical Methods**

Means, standard deviations (SDs), and coefficients of variation (CVs) were calculated for each variable. Pearson product correlation coefficients were used to assess the relationship of each independent variable (VO_{2max}, RE, VT, v_{MART}, v_{50m}) with the dependent measure of the v_{5km}. A backward step-wise multiple-linear-regression analysis was used to determine the variance in v_{5km} explained by each independent variable. Variables were expressed as a velocity (v_{MART}, v_{50m}, v_{5km}) to keep units constant between variables and to be consistent with others’ studies.8,10,12 Statistical significance was accepted as P < .05. All statistical analyses were done using SPSS 12.0 (SPSS Inc, Chicago, IL).

**Results**

Table 2 depicts the group means, SDs, and CVs for the selected physiological determinants (VO_{2max}, RE, VT, v_{MART}, v_{50m}) and 5-km-race performance. The group was relatively homogeneous in their aerobic, anaerobic, and performance measures, with the CV for these variables ranging from 4.04 to 10.84.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
<th>CV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-km time (min)</td>
<td>v_{5km} (m/s)</td>
<td>VO_{2max} (mL · kg⁻¹ · min⁻¹)</td>
</tr>
<tr>
<td>20.13 ± 1.59</td>
<td>4.16 ± 0.32</td>
<td>54.24 ± 5.88</td>
</tr>
</tbody>
</table>

Abbreviations: CV, coefficient of variation; v_{5km}, mean velocity of the 5-km time trial; VO_{2max}, maximal oxygen uptake; RE, running economy at 3.56 m/s; VT, ventilatory threshold; v_{MART}, peak velocity in the maximal anaerobic running test; v_{50m}, mean velocity in the 50-m sprint.

The backward step-wise multiple-regression analysis revealed that the combination of VO_{2max}, v_{MART}, and VT accounted for 81% of the total variance seen in the v_{5km} (R² = .81, P < .001). VO_{2max} accounted for most (48%) of the variability in the v_{5km} and the v_{MART} and VT explained the remaining 31% and 2%, respectively.

**Discussion**

Bassett and Howley2 state that the ability to maintain high-endurance running velocity is associated with oxidative ATP production, and to argue that anaerobic sources of ATP are important to endurance performance is “a clear impossibility.” We do not deny that a high VO_{2max} is a prerequisite to endurance-racing success but suggest that anaerobic ATP production, though only a small fraction of the total, may still be vital to performance, particularly among homogeneous groups of runners such as college or postcollege competitors. This concept has often been overlooked. Berg18 states that this relative neglect of the anaerobic systems may be a possible research limitation when predicting endurance performance. This is made evident when searching the literature for determinants of distancing-running success. A vast number of articles can be found that have assessed aerobic determinants

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**Table 2 Physiological and Performance Characteristics of the Runners (N = 13)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
<th>CV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-km time (min)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>v_{5km} (m/s)</td>
<td>4.16 ± 0.32</td>
<td>7.69</td>
</tr>
<tr>
<td>VO_{2max} (mL · kg⁻¹ · min⁻¹)</td>
<td>54.24 ± 5.88</td>
<td>10.84</td>
</tr>
<tr>
<td>RE (mL · kg⁻¹ · min⁻¹)</td>
<td>39.40 ± 2.10</td>
<td>5.33</td>
</tr>
<tr>
<td>VT (%VO_{2max})</td>
<td>74.54 ± 7.83</td>
<td>10.50</td>
</tr>
<tr>
<td>v_{MART} (m/s)</td>
<td>4.95 ± 0.20</td>
<td>4.04</td>
</tr>
<tr>
<td>v_{50m} (m/s)</td>
<td>6.89 ± 0.28</td>
<td>4.06</td>
</tr>
</tbody>
</table>

Abbreviations: CV, coefficient of variation; v_{5km}, mean velocity of the 5-km time trial; VO_{2max}, maximal oxygen uptake; RE, running economy at 3.56 m/s; VT, ventilatory threshold; v_{MART}, peak velocity in the maximal anaerobic running test; v_{50m}, mean velocity in the 50-m sprint.

**Table 3 Pearson Correlations for the Selected Physiological Determinants and v_{5km} (m/s)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Correlation</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO_{2max} (mL · kg⁻¹ · min⁻¹)</td>
<td>.80</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>RE (mL · kg⁻¹ · min⁻¹)</td>
<td>.42</td>
<td>NS</td>
</tr>
<tr>
<td>Ventilatory threshold (%VO_{2max})</td>
<td>.05</td>
<td>NS</td>
</tr>
<tr>
<td>v_{MART} (m/s)</td>
<td>.69</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>v_{50m} (m/s)</td>
<td>.31</td>
<td>NS</td>
</tr>
</tbody>
</table>

Abbreviations: v_{5km}, mean velocity of the 5-km time trial; VO_{2max}, maximal oxygen uptake; RE, running economy at 3.56 m/s; v_{MART}, peak velocity in the maximal anaerobic running test; v_{50m}, mean velocity in the 50-m sprint; NS, not significant.
(VO2max, RE, VT, etc), while the research analyzing anaerobic factors is limited to less than 10 articles.

The purpose of this study was to examine the relationship between anaerobic characteristics and 5-km-race performance in trained female cross-country runners. This inquiry was addressed by measuring the runners’ anaerobic work capacity and power using the v_MART, the v_S50m, and race performance from a 5-km time trial. The regression analysis revealed that the v_MART explained a significant amount of the shared variance seen in the v_S50m, accounting for 31% of the total 81%, with VO2max and VT accounting for the remaining 50%. These results are in agreement with those of Bulbulian et al.6 who reported that 76% of the variance seen in 8-km-race time in 12 male NCAA Division I cross-country runners could be explained by the same physiological characteristics. Anaerobic work capacity, determined by the Monod critical power test, accounted for 58% of the total shared variance, while the remaining 17% was explained by the combination of VO2max and VT. Paavolainen et al8 reported slightly different findings. They found that the v_MART explained a significant amount of the total variance, but not to the same extent as seen in the current study or that of Bulbulian et al. Among their 17 male endurance athletes, the combination of the respiratory-compensation threshold (55%), RE (15%), and the v_MART (15%) could account for 85% of the variance in the v_S5km. Although it may be difficult to compare the results of the aforementioned studies because of differences in subjects (gender, training status, etc), race distances, and measures of anaerobic power or capacity, all these studies do have one thing in common—that is, in addition to aerobic factors, one’s ability to produce ATP anaerobically may contribute to race performance among runners with matched abilities.

In addition to the v_MART’s entering the regression analysis, it significantly correlated to the v_S5km (r = .69, P < .01). Nummela et al10 and Paavolainen et al8 reported similar correlations (r = .68 and .77, P < .01 and .001) between the v_MART and the v_S5km in trained male athletes. Rusko et al12 have suggested that the v_MART is influenced by not only anaerobic metabolism but also neuromuscular characteristics and that it can be used to measure the so-called muscle-power factor. Muscle-power factor has been defined as the ability of the neuromuscular system to produce power during maximal exercise when glycolytic and oxidative energy production are high and muscle contractility may be limited.8 The current findings would seem to support the muscle-power-factor concept, but this was not the main intent of the study. The v_MART was selected primarily for its ability to estimate anaerobic work capacity, thus revealing that the cited correlations reflect a positive relationship between anaerobic metabolism and race performance.

We also found that VO2max significantly related to the v_S5km (r = .80, P < .01). This is not surprising, seeing that VO2max had the largest CV compared with all other variables. Bassett and Howley1,2 suggest that correlations will approach zero if the range for VO2max is too narrow and that VO2max will not be a good predictor of success in runners with similar VO2max values. This has been confirmed by Bulbulian et al8 and rejected by Houmard et al11 and Paavolainen et al. This discrepancy could be due to the anaerobic VO2max values actually are. The runners in the current study were not as homogeneous, as shown by the SDs and CVs, as in the other studies.6–8 This implies that VO2max is still a significant predictor of race performance in runners who are relatively matched in regard to their aerobic abilities.

Another notable finding was that the v_S50m did not correlate to performance when the v_MART did (r = .31, P = .30 vs r = .69, P < .01). This is most likely due to the differences between these 2 anaerobic tests, the v_S50m being a test of anaerobic power and the v_MART a test of anaerobic work capacity. The 50-m sprint lasted less than 8 seconds and the MART between 96 and 130 seconds of intermittent sprinting, meaning the v_MART most likely stressed both immediate energy stores (creatine phosphate and stored ATP) and the glycolytic pathway, while the 50-m sprint was too short to have the same energetic impact. The v_MART has also been shown to correlate with the maximal accumulated oxygen deficit19 and 400-m sprint time12 and to elicit high blood lactate concentrations.8,12,13 These results suggest that anaerobic work capacity may be more of a determinant of endurance performance than anaerobic power.

From a practical perspective, the current findings and those of others suggest that anaerobic metabolism contributes to endurance performance.5–10 A distance runner’s ability to synthesize ATP anaerobically may be used to obtain a good position at the start, make a critical pass, react to an explosive breakaway move, or sprint to the finish line. Baumann and Wetter20 found that anaerobic peak power measured by the Wingate test significantly declined across an 8- to 10-week cross-country season in 8 male Division III runners. However, the extent to which this drop in power affected race performance was not examined. The work done by Paavolainen et al21 demonstrated that explosive strength training improved the anaerobic characteristics (identified by the v_MART and 20-m velocity) of 12 male cross-country runners. The increase in the v_MART correlated to these participants’ running faster in a 5-km time trial. It is therefore recommended that coaches and athletes develop workouts that stress the anaerobic systems, specifically in runners who are aerobically matched or have focused only on maximizing their aerobic systems.7

One such method of improving anaerobic characteristics may be to follow a training regimen similar to the one Paavolainen et al21 used on the 12 male cross-country runners mentioned earlier. For 9 weeks those runners replaced 32% of their normal training hours, which consisted predominantly of endurance running, with sport-specific strength training. These sessions lasted 15 to 90 minutes and included sprint repeats, jumping exercises, and leg-press and knee-extensor–flexor exercises done at high or maximal movement velocities with low loads (0% to 40% of 1-repetition maximum).21 These exercises may
increase the muscle’s ability to produce ATP anaerobically and should not be neglected, but it is important to remember that aerobic determinants (VO$_2$max, RE, VT, etc) are essential to successful distance running.

In summary, this was the first study to examine the relationship between anaerobic characteristics and race performance among female college cross-country runners. It was demonstrated that the $v_{\text{MART}}$ was significantly related to the $v_{5\text{km}}$ and accounted for a significant amount of the shared variance seen in race performance. These findings suggest that aerobically trained female runners’ ability to produce ATP through the immediate and glycolytic pathways could be an effective discriminator of velocity and outcome in a 5-km race.

Acknowledgments
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References