International Journal of Sports Physiology and Performance, 2012, 7, 170-174

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_{2max}), running economy, and ventilatory threshold (VT). ***Results:*** Both the v_{MART} ($r = .69$, $P < .01$) and VO_{2max} ($r = .80$, $P < .01$) correlated with the mean velocity of the 5-km (v_{5km}). A multiple-linear-regression analysis revealed that the combination of VO_{2max}, 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_{2max} 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

Aerobic-energy determinants such as maximal oxygen uptake (VO_{2max}), fractional utilization of VO_{2max}, and running economy (RE) have long been associated with successful distance running,[1,2] whereas the role of anaerobic power or capacity has often been overlooked. Though it is widely accepted that most of the adenosine triphosphate (ATP) hydrolyzed in a distance event is synthesized through oxidative means and that a high VO_{2max} is a prerequisite to success, VO_{2max} does not account for all the variance seen in race time. This had led some to speculate that anaerobic power or capacity may play a larger role than previously believed, particularly during middle-distance events (1500-m to 5-km) that are commonly performed at 90% to 100% VO_{2max}[3,4] or races achieving intensities greater than lactate threshold.[5] While the research examining the role of anaerobic metabolism in distance events is scarce, the general conclusions are that anaerobic characteristics positively influence performance and are very effective discriminators of 5- to 10-km-race time or velocity.[5–10]

Bulbulian et al[6] concluded that among aerobically well-matched male cross-country runners tightly clustered in a race, the finishing order may be determined by the runners' ability to produce energy anaerobically during or near the end of the event. Besides a sprint finish, rapid synthesis of ATP through the anaerobic pathways may be used to obtain a good position at the start, to make a critical pass, or to react to an explosive breakaway move. Joyner and Coyle[11] suggest that the rate of total ATP turnover during an endurance race reflects an interplay of aerobic and anaerobic metabolism, with lactate production serving to maintain reducing agents for continued glycolysis and generation of pyruvate. Regardless of how the anaerobic systems affect performance, either rapid ATP production or maintenance of oxidative phosphorylation, it must be understood that success in distance running requires a high capacity to generate ATP aerobically and that the addition of anaerobic power or capacity may influence the outcome of the race.

The results of the previous studies strongly suggest that measurements of anaerobic ability be included in future examinations of distance-running performance. However, only 1 of those studies analyzed the aerobic and anaerobic properties of female runners. The work done by Tharp et al[5] demonstrated that the combination of ventilatory threshold (VT) and 50-m-sprint time best explained the variance in 10-km road-race time in 14 recreational runners. However, little research has been done on highly trained female runners or has used the maximal anaerobic running test (MART) in this particular population. The MART, a laboratory treadmill test, was specifically developed to assess both the metabolic and the neuromuscular components of maximal anaerobic

The authors are with the Dept of Kinesiology and Health, Georgia State University, Atlanta, GA.

performance in runners.[12] The anaerobic-energy contributions of the MART have been reported to range from 64% to 72%[13] and 70% to 80%.[14] 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 VO_{2max}, 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.[8]

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.

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

Variable	Mean ± SD
Age (y)	20.5 ± 2.1
Height (cm)	163.3 ± 6.0
Mass (kg)	58.7 ± 5.7
Body fat (%)	24.2 ± 4.3
Running experience (y)	7.1 ± 2.3
Training (km/wk)	60.0 ± 12.1

Maximal Aerobic-Power Test

VO_{2max}, 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 VO_2 was achieved. Steady state was defined as a change in VO_2 not exceeding ±2.5 $mL \cdot kg^{-1} \cdot min^{-1}$ in any 2 consecutive minutes[15]; the mean VO_2 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.[5] VT was determined using the computerized V-slope method[16] and expressed as a percentage of VO_{2max}. VO_{2max} was taken as the highest mean of 2 consecutive 15-s VO_2 measurements ($mL \cdot kg^{-1} \cdot min^{-1}$).

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%.[12,17] Exhaustion in the MART was determined as the time 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.

Correlation coefficients for the selected physiological determinants and the v_{5km} are shown in Table 3. The v_{MART} and VO_{2max} significantly correlated with the v_{5km}, while no significant relationships were observed for RE, VT, and v_{50m}.

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

Variable	Mean ± SD	CV (%)
5-km time (min)	20.13 ± 1.59	7.90
v_{5km} (m/s)	4.16 ± 0.32	7.69
VO_{2max} ($mL \cdot kg^{-1} \cdot min^{-1}$)	54.24 ± 5.88	10.84
RE ($mL \cdot kg^{-1} \cdot min^{-1}$)	39.40 ± 2.10	5.33
VT (%VO_{2max})	74.54 ± 7.83	10.50
v_{MART} (m/s)	4.95 ± 0.20	4.04
v_{50m} (m/s)	6.89 ± 0.28	4.06

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)

Variable	Correlation	P
VO_{2max} ($mL \cdot kg^{-1} \cdot min^{-1}$)	.80	<.01
RE ($mL \cdot kg^{-1} \cdot min^{-1}$)	.42	NS
Ventilatory threshold (%VO_{2max})	.05	NS
v_{MART} (m/s)	.69	<.01
v_{50m} (m/s)	.31	NS

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.

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} ($R^2 = .81$, $P < .001$). 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 Howley[2] 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. Berg[18] 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

(VO_{2max}, 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_{50m}, 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_{5km}, accounting for 31% of the total 81%, with VO_{2max} 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 VO_{2max} and VT. Paavolainen et al[8] 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.[6] 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_{5km}. 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_{5km} ($r = .69$, $P < .01$). Nummela et al[10] and Paavolainen et al[8] reported similar correlations ($r = .68$ and $.77$, $P < .01$ and $.001$) between the v_{MART} and the v_{5km} in trained male athletes. Rusko et al[12] 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 VO_{2max} significantly related to the v_{5km} ($r = .80$, $P < .01$). This is not surprising, seeing that VO_{2max} had the largest CV compared with all other variables. Bassett and Howley[1,2] suggest that correlations will approach zero if the range for VO_{2max} is too narrow and that VO_{2max} will not be a good predictor of success in runners with similar VO_{2max} values. This has been confirmed by Bulbulian et al[6] and rejected by Houmard et al[7] and Paavolainen et al.[8] This discrepancy could be due to how similar the VO_{2max} 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 VO_{2max} 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_{50m} 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_{50m} 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 that 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 deficit[19] and 400-m sprint time[12] 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 Wetter[20] 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 al[21] 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 al[21] 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_{2max}, 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_{MART} was significantly related to the v_{5km} 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

The authors would like to thank the runners and coaches of the Georgia State University cross-country program who helped make this study possible.

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