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Relationship between 800-m running performance and running economy during high-intensity running in well-trained middle-distance runners

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Abstract Running economy (RE) at an intensity above the lactate threshold (LT) is reported to be the most important aerobic capacity for estimating 1,500-m running performance. The reason that the RE at intensity better reflects the energy metabolism during a 1,500-m run, is that it is performed above the LT intensity running. This study clarified the relationship between an 800-m run, which is performed above the LT intensity, and aerobic capacities, including the RE measured at intensities below and above the LT. This study included 12 well-trained male middle-distance runners (800-m velocity: 25.5 ± 0.5 km·h⁻¹, LT intensity: 79.7 ± 5.1% maximal oxygen uptake [VO₂max]). Both the RE of below and above the LT intensity were calculated at 65%VO₂max (RE₆₅) and 90%VO₂max (RE₉₀). The 800-m velocity was not related to the VO₂max or the LT intensity (r = -0.16 and -0.10, respectively). This velocity correlated with both RE₆₅ and RE₉₀, with the correlation coefficient being higher for RE₉₀ (r = -0.80 vs -0.75). Furthermore, the coefficient of determination for the 800-m velocity determined from VO₂max, LT intensity and RE₉₀ was higher than that determined from VO₂max, LT intensity and RE₆₅ (R² = 0.522 vs 0.428, P = 0.03 vs 0.06). Based on these results, we concluded that the RE at an intensity above the LT might be better than other aerobic capacities for estimating the 800-m running performance, and more than 50% of this performance can be explained by VO₂max, LT intensity and RE at an intensity above the LT.

Keywords: middle-distance running, athletes, energy metabolism, lactic acid, oxygen

Introduction

Variability in between-subject distance running performance is explained by three aerobic capacities: maximal oxygen uptake (VO₂max), lactate threshold (LT) intensity and running economy (RE)¹. In particular, distance running performance has been observed to have a strong relation with the RE in well-trained runners² and highly trained athletes³. In addition, Tanji et al.⁴ reported that 1,500-m running performance had a stronger relationship with the RE at an intensity above the LT (RE₉₀) than the RE at an intensity below the LT (RE₆₅) in well-trained distance runners. They suggested that the RE₉₀ was better reflected in the energy metabolism during 1,500-m running that requires approximately 20% anaerobic energy metabolism⁵, compared to RE₆₅. Energy metabolism during 800-m running requires 40% anaerobic energy metabolism⁶; however, a significant relationship between 800-m running performance and the RE₉₀ has not been clarified.

Materials and Methods

Subjects. The study included 12 male middle-distance runners (age: 19.9 ± 0.9 years, height: 170.1 ± 4.6 cm, body weight: 58.7 ± 3.1 kg, body fat: 7.8 ± 1.4%). In addition, the 800-m running performance of subjects was decided by best race results within 3 months before the laboratory tests. The 800-m running performance was 1′53″1 ± 2″1, and an average velocity over 800 m (800-m velocity) was equivalent to 25.5 ± 0.5 km·h⁻¹. After being informed of the purpose of this study, all the subjects provided written informed consent, prior to participation. The study was approved by the Research Ethics Com-

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mittee at the University of Tsukuba Graduate School of Comprehensive Human Sciences (Issue Number: 27-27).

Experimental protocol and calculated values. The subjects ran on a treadmill (ORK-7000; Ohtake-Root Kogyo Co., Ltd, Iwate, Japan) at a 1% grade. They performed two tests separated by 2-3 days.

The first test was a multi-intermittent incremental load test, which determined the VO₂max and LT intensity. The velocity for the initial stage was 12.6 km·h⁻¹ (only one subject was at 10.2 km·h⁻¹), depending on the subject’s running performance, and was increased by 1.2 km·h⁻¹ at each subsequent stage up to a total of six stages. Each stage consisted of 3-min running and 2-min rest. After six-stage running, they rested for 5 min and then performed continuous incremental load running with the velocity increased by 0.6 km·h⁻¹ per min until subjects reached exhaustion.

The second test was a submaximal running test, which determined the RE. Subjects ran for 4 min at 6 km·h⁻¹ as a warmup and at 65%, 70%, 75%, 80%, 85% and 90% VO₂max intensity, calculated based upon the first test results, with a 2-min rest between each velocity.

Expired gas was analyzed breath-by-breath for VO₂, VCO₂, pulmonary ventilation and respiratory exchange ratio (RER) using the computerized standard open circuit technique with an expired gas analyzer (AE310-S Aero monitor; Minato Medical Science Co., Ltd, Osaka, Japan). The gas analyzer was calibrated using a calibration gas (air equivalent: 20.90% O₂, 0.03% CO₂, balance N₂; exhalation equivalent: 15.00% O₂, 5.00% CO₂, balance N₂), and the flow sensor was calibrated with a flow calibrator (ACA105, 2L) before and after the measurement. To measure bLa, a fingertip blood sample was taken from the subject before the first test, after each stage of running, and at 1, 3 and 5 min of exhaustion, and analyzed with a lactate analyzer (1500 SPORT lactate analyzer; Yellow Springs Inc., Yellow Springs, OH, USA). The measurement room was ventilated continually throughout the experiment.

Data analysis. VO₂max was defined as the greatest oxygen uptake over a 1-min period during the test. The subject’s velocity at VO₂max (vVO₂max) was calculated by substituting the VO₂max into the velocity-VO₂ regression equation. The velocity at the LT (vLT) was determined using the lactate threshold decision method (Lactate-E) by Newell et al.7. The LT intensity (LTI) was determined from vLT and vVO₂max. vLT correlates well with performance because it is dependent on both VO₂max and RE; hence, Hoff et al.8 claimed that a “true” LT is determined in the percentage of VO₂max. VO₂, VCO₂ and RER were defined as the averages of the breath-by-breath data over the final 1 min at each running velocity. The RE was calculated at two intensities, at 65%VO₂max (RE₆₅) defined as below the LT and 90%VO₂max (RE₉₀) defined as above the LT, using the method described by Tanji et al.6.

Statistical analyses. Statistical analyses were performed using SPSS version 22 (IBM Corp., Armonk, NY, USA). The relationship between the 800-m velocity (used as the measure of running performance) and aerobic capacities were investigated using Pearson’s correlation coefficients. Multiple regression analysis was applied to the 800-m velocity as the dependent variable and the three aerobic capacities (VO₂max, LTI and either RE₆₅ or RE₉₀) as independent variables. Data are expressed as mean ± SD. The level of significance was set at P < 0.05.

Results

VO₂max, vVO₂max, vLT and LTI did not significantly correlate with the 800-m velocity (r = -0.19, 0.44, 0.19 and -0.10, respectively); however, RE₆₅ and RE₉₀ showed a significant negative correlation (r = -0.75, and -0.80, respectively) (Table 1). Notably, RE₉₀ showed a stronger

|                      | Mean ± SD | r
|----------------------|-----------|--------
| VO₂max (mL·kg⁻¹·min⁻¹) | 67.4 ± 5.3 | -0.16 |
| vVO₂max (km·h⁻¹)         | 19.1 ± 1.0 | 0.44   |
| vLT (km·h⁻¹)            | 15.2 ± 1.3 | 0.19   |
| LTI (%VO₂max)           | 79.7 ± 5.1 | -0.10  |
| RE₆₅ (J·kg⁻¹·m⁻¹)       | 4.41 ± 0.25 | -0.75** |
| RE₉₀ (J·kg⁻¹·m⁻¹)       | 4.71 ± 0.27 | -0.80** |

Notes: VO₂max, maximal oxygen uptake; vVO₂max, velocity of maximal oxygen uptake; vLT, velocity of lactate threshold; LTI, lactate threshold intensity; RE₆₅, running economy at 65% maximal oxygen uptake intensity (12.4 ± 0.7 km·h⁻¹); RE₉₀, running economy at 90% maximal oxygen uptake intensity (17.2 ± 0.9 km·h⁻¹); **, P < 0.01
correlation with the 800-m velocity than RE65 (Fig. 1). Multiple regression analysis with the 800-m velocity as the dependent variable and VO₂max, LTI and either RE65 or RE90 as the independent variables showed significant relationships ($R^2 = 0.428$ and $0.522$; $P = 0.06$ and $0.03$). The correlation was stronger when using VO₂max, LTI, and RE90 (VIF = 1.187, 1.153 and 1.053, respectively).

Discussion

Maximal aerobic energy capacity (VO₂max) is suggested to be an important aerobic capacity for the 800-m run when compared to the economical capacity (RE)⁹. In this study, VO₂max of subject (800-m running performance: 1'53"1 ± 2"1) was 67.4 ± 5.3 mL·kg⁻¹·min⁻¹. This VO₂max is higher than that in the study of Deason et al.¹⁰ (61.6 ± 5.1 mL·kg⁻¹·min⁻¹), which studied lower competitive-level runners (2'12"6 ± 7"3), and lower than those in the studies of Lacour et al.¹¹ (69.5 ± 4.4 mL·kg⁻¹·min⁻¹) and Ingham et al.⁹ (72.4 ± 2.4 mL·kg⁻¹·min⁻¹), which focused on higher competitive-level runners (1'51"1 ± 2"7 and 1'48"9 ± 2"4, respectively). Thus, VO₂max of the present study subjects is considered an appropriate value from their performance and these study results.

However, the results of this study show a strongly relation between the 800-m velocity and the RE rather than the VO₂max in well-trained middle-distance runners. This result coincides with previous long-distance running findings, which reported that the RE is more important than the VO₂max in well-trained long-distance runners²,³. The study of Tanji et al.⁴ showed a strong relationship between 1,500-m running performance and the RE ALT compared to the RE bLT in well-trained distance runners. Tanji et al. suggest that the capacity of conservation of the energy cost with running at a higher velocity leads to success in a 1,500-m run, since it increases the running velocity in the final phase. The RE ALT is more reflective of the energy metabolism during a 1,500-m run. This study clarified the relationship with 800-m run performance, which requires a larger contribution from anaerobic energy metabolism during a run (approximately 40%)⁵, and also showed a strong relationship between 800-m running performance and the RE ALT compared to the RE bLT ($r = -0.80$ vs -0.75). The $r$ value is the effect size when analyzing the relationship between two variables. Therefore, this result can be considered that RE ALT is more closely related to 800-m running performance than RE bLT. Running velocity during an 800-m run is accelerated from the start to 200 m, and then gradually decreases until the goal¹². It is more important to maintain the running velocity than to produce the maximal energy metabolism. Kadono et al.¹² showed a significantly higher running velocity in the final phase during an 800-m run of elite runners compared to sub-elite level runners at the same performance level as subjects of the present study. Thus, whether or not one can run economically at higher running velocity, RE ALT can explain the 800-m running performance for subjects at the present study performance level.

In addition, the results of the multiple regression analysis using the three aerobic energy metabolism capacities (i.e. VO₂max, LTI and RE) showed that the variation in 800-m velocity between the subjects was over 50%.
This value of determining the coefficient is on the small side, but fairly consistent with the contribution rate of the aerobic energy metabolism during an 800-m run (approximately 60%)\(^5\). These results show that \( \text{RE}_{\text{at}} \) is also a useful variable to estimate 800-m running performance.

However, the difference in correlation coefficient between the 800-m velocity and \( \text{RE} \) at each intensity is small, suggesting that the \( \text{RE} \) should be evaluated at greater than 90% of the \( \dot{V}O_2\text{max} \) intensity to best estimate 800-m running performance. Investigation of the \( \text{RE} \) at a higher intensity than 100%\( \dot{V}O_2\text{max} \) would be better for estimating the 800-m running performance since the running intensity during an 800-m run exceeds 100%\( \dot{V}O_2\text{max} \). In this case, however, running time would be shorter, which may not satisfy the definition of \( \text{RE} \); the definition of \( \text{RE} \) being “the steady-state oxygen consumption (\( \dot{V}O_2 \)) at a given running velocity.” Thus, the economy at an intensity above 100%\( \dot{V}O_2\text{max} \) should not be expressed as the \( \text{RE} \), but a different indicator (e.g. sprint economy). In addition, more research should be completed on improving the 800-m running performance factors by evaluating the anaerobic energy metabolism capacities (i.e. maximal accumulated oxygen deficit and/or accumulated blood lactate concentration).

**Conclusion**

\( \text{RE} \) has a significant relationship with 800-m running performance in well-trained middle-distance runners, particularly at an intensity above the \( \text{LT} \). Of the variation in 800-m velocity among subjects, over 50% was explained by \( \dot{V}O_2\text{max} \), \( \text{LTI} \) and the \( \text{RE} \) at an intensity above the \( \text{LT} \). These results suggest that the \( \text{RE} \) at an intensity above the \( \text{LT} \) is an important aerobic capacity for estimating 800-m running performance.

**Conflict of Interests**

The authors declare that they have no conflict of interest in the authorship and publication of this article.

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