Relationship between 800-m Running Performance and Aerobic and Anaerobic Energy Metabolism Capacities in Well-Trained Middle-Distance Runners

800-m Running Performance and Energy Metabolism Capacities

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Abstract

The aim of this study was to elucidate the relationship between the 800-m running performance and aerobic and anaerobic energy metabolism capacities in well-trained middle-distance runners. This study was conducted on 12 male middle-distance runners (age 19.7 ± 0.9 years, height 170.0 ± 4.6 cm, body weight 58.9 ± 3.0 kg, body fat 7.8% ± 1.2%, 800-m season best time 1'53"2 ± 2"2 and equivalent to an average velocity of 25.4 ± 0.4 km·h⁻¹ over 800 m). Participants underwent three running tests on a treadmill to assess aerobic (maximal oxygen uptake [VO₂max], lactate threshold intensity [LTI], running economy [RE]) and anaerobic (maximal accumulated oxygen deficit [MAOD] and maximal accumulation blood lactate concentration [ΔbLa]) energy metabolism capacities. The results demonstrated a significantly negative relationship between the 800-m running velocity and RE and MAOD (r = −0.78 and −0.72, respectively), but not with VO₂max, LTI, and ΔbLa (r = −0.16, −0.17 and 0.11, respectively). Furthermore, this study demonstrated that >70% of the 800-m running velocity could be explained by RE, LTI, and ΔbLa. These results suggest that RE affects the 800-m running performance in well-trained runners.

Keywords: 800-m running, aerobic energy capacity, anaerobic energy capacity, homogeneous performance
1. Introduction

Performances at long-distance running events, which require >80% of the overall energy expended by aerobic energy metabolism (Hill, 1999; Weyand et al., 1993), are associated with aerobic capacities, such as maximal oxygen uptake (\( \dot{\text{VO}}_{2}\text{max} \)), lactate threshold (LT), and running economy (RE) (Midgley et al., 2007). RE is defined as an energy metabolism for a given running velocity; lower energy metabolism can be evaluated as greater RE. Lately, many researchers have illustrated the impact of variable RE on the running performance of highly competitive and/or homogeneous runners (Conley and Krahenbuhl, 1980; Morgan et al., 1989). Recently, Tanji et al. (2017a) have demonstrated that \( \dot{\text{VO}}_{2}\text{max} \) and RE can explain by >60% of 1,500-m running performance, especially by RE at high-intensity, rather than low-intensity running.

Conversely, the 800-m running performance, which requires 60% and 40% of the overall energy expended by aerobic and anaerobic energy metabolisms, respectively (Duffield et al., 2005; Hill, 1999). For example, Nevill et al. (2008) and Ramsbottom et al. (1994) demonstrated a significantly positive relationship between the 800-m running performance and \( \dot{\text{VO}}_{2}\text{max} \) and maximal accumulated oxygen deficit (MAOD). However, their results were based on studies conducted on heterogeneous performance runners (CV, >10.0%), with both male and female participants. In male heterogeneous runners (CV, >8.0%), running performance is associated with \( \dot{\text{VO}}_{2}\text{max} \) (Bosquet et al., 2007a), but not with MAOD (Bosquet et al., 2007a; 2007b). Thus, maximal aerobic (\( \dot{\text{VO}}_{2}\text{max} \)) and anaerobic (MAOD) energy metabolism capacities are partly determinant factors of 800-m running performance.
In contrast, no significant relationship has been observed between the 800-m running performance and VO\textsubscript{2max} (Craig and Morgan, 1998; Lacour et al., 1990b, Tanji et al., 2017b) and MAOD (Craig and Morgan, 1998) in homogeneous runners (CV, 3.0%, 2.4% and 1.9%, respectively). In addition, in well-trained runners (CV, 1.9%), Tanji et al. (2017b) demonstrated that the 800-m running performance had a negative relationship with RE but not with VO\textsubscript{2max}. Only, Ingham et al. (2008) observed that the 800-m running performance had a positive relationship with VO\textsubscript{2max} in highly competitive runners (CV, 2.2%). However, both Ingham et al. (2008) and Lacour et al. (1990b) did not observe a significant relationship in 800-m running performance with RE. Moreover, the studies by Ingham et al. (2008), Lacour et al. (1990b), and Tanji et al. (2017b) did not investigate the relationship between 800-m running performance and anaerobic capacity. Results of the above mentioned research indicate that highly trained and homogeneous (CV, <5.0%) 800-m runners show different relationships in running performance with aerobic and anaerobic energy metabolism capacities compared with heterogeneous performance runners.

Overall, a consensus on energy metabolism capacity explaining the inconstant running performance in highly trained and homogeneous runners, especially between aerobic capacity and 800-m running performance, has not been attained. Moreover, MAOD may not be related with 800-m running performance in highly trained and homogeneous runners (CV, <5.0%; Craig and Morgan, 1998). However, the anaerobic capacity can be evaluated by not only MAOD but also maximal accumulation blood lactate concentration (ΔbLa; Vandewalle et al., 1987). Lacour et al. (1990a) demonstrated the relationship between ΔbLa by the race and both 400-m and 800-m
running performances in highly trained male runners, suggesting that a higher ΔbLa is associated with a superior 800-m running performance. Perhaps, a comprehensive analysis could suggest the training regimen that homogeneous 800-m runners should undergo to improve their performance.

Hence, the objective of this study was to elucidate the relationship between the 800-m running performance and aerobic and anaerobic energy metabolism capacities in well-trained middle-distance runners. We hypothesized that 800-m running performance related to RE and ΔbLa but not with other energy metabolism capacities.

2. Materials and Methods

2.1. Subjects

This study enrolled 12 male middle-distance runners (age, 19.7 ± 0.9 years; height, 170.0 ± 4.6 cm; body weight, 58.9 ± 3.0 kg; body fat, 7.8% ± 1.2%; 800-m season best time, 1′53″2 ± 2″2 [CV, 1.9%]; and equivalent to an average velocity of 25.4 ± 0.4 km·h⁻¹ over 800 m). Before participation, all participants provided written informed consent after being informed of the purpose of this study. The study was approved by the Research Ethics Committee at the University of Tsukuba Graduate School of Comprehensive Human Sciences (Issue Number: 27–27).

2.2. Experimental protocol and calculated values

All participants underwent three running tests, wherein they ran on a treadmill (ORK-7000; Ohtake-Root Kogyo Co., Ltd., Iwate, Japan) at 1% grade. All tests were conducted in the afternoon.
2.2.1. Maximal test.

All participants performed a six-stage intermittent incremental load running (3-min running and 2-min rest) to evaluate their LT intensity (LTI). The initial stage velocity was set at 12.6 km·h⁻¹ (only one runner was at 10.2 km·h⁻¹) and was increased by 1.2 km·h⁻¹ at each stage. 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 they reached exhaustion to measure their VO₂max. Exhaustion was determined when runners reached their age-predicted maximal heart rate (HR; ≥220–age), the respiratory exchange ratio (RER) exceeded 1.15, or bLa exceeded 8.00 mmol·L⁻¹ (Fletcher et al., 2009).

2.2.2. Submaximal test.

The submaximal test was conducted 2 or 3 days after the maximal test to assess the runners’ RE at 90% VO₂max intensity (Tanji et al., 2017b). Participants did warm-up running for 4 min at 6 km·h⁻¹ and then ran at 65%, 70%, 75%, 80%, 85%, and 90% VO₂max intensity, calculated according to the maximal test results, with 2-min rest between each velocity.

2.2.3. Supramaximal test.

The supramaximal test was conducted on the same day as the submaximal test to measure their MAOD after the HR, rating of perceived exertion, VO₂, and bLa confirmed that participants had recovered and returned to a resting state (after an
approximately 1–2-h rest). Each runner selected the running velocity (velocity of the supramaximal test \(v_{\text{ST}}\), 121.7\% ± 4.4\% \(\dot{\text{VO}}_{\text{2}}\max\)) to reach exhaustion after approximately 2–3 min (Noordhof et al., 2010).

### 2.3. Experimental instruments and measurement methods

Expired gas was assessed by the \(\dot{\text{VO}}_{\text{2}}\), carbon dioxide excretion (\(\dot{\text{CO}}_{\text{2}}\)), pulmonary ventilation (\(\dot{\text{V}}\text{E}\)), and RER using the breath-by-breath computerized standard open circuit technique with an expired gas analyzer (AE310-S Aero Monitor; Minato Medical Science Co., Ltd., Osaka, Japan). The gas analyzer and flow sensor were calibrated using the calibration gas (air equivalent: 21.00\% \(\text{O}_{2}\), 0.03\% \(\text{CO}_{2}\), and balance \(\text{N}_{2}\); exhalation equivalent: 15.00\% \(\text{O}_{2}\), 5.00\% \(\text{CO}_{2}\), and balance \(\text{N}_{2}\)) and a flow calibrator (2 L), respectively. Experiments were conducted in a continuously ventilated room. Before the test, after each running stage, and after 1, 3, and 5 min of exercise to exhaustion, a fingertip blood sample was obtained for bLa measurement (1500 SPORT Lactate Analyzer; Yellow Springs Inc., Yellow Springs, OH, USA). The HR was measured using an HR monitor (Polar RCX5; Polar Electro Japan, Tokyo, Japan). In addition, laboratory temperature and humidity were controlled at 24–26°C and 50\%–60\%, respectively, with continuous ventilation throughout the experiment.

### 2.4. Data analysis

\(\dot{\text{VO}}_{\text{2}}\max\) was defined as the highest oxygen uptake during 1 min in the continuous incremental load test. The velocity at \(\dot{\text{VO}}_{\text{2}}\max\) (\(v\dot{\text{VO}}_{\text{2}}\max\)) was calculated with substituted \(\dot{\text{VO}}_{\text{2}}\max\) into the velocity–\(\dot{\text{VO}}_{\text{2}}\) regression equation from the
intermittent incremental load test data. Velocity at LT (vLT) was determined by the lactate analysis software (Lactate-E; Newell et al., 2007). LTI was determined from vLT and v\dot{\text{VO}}_{2}\text{max}, and RE was calculated using the method described by Tanji et al. (2017a).

The velocity–\dot{\text{VO}}_{2} regression of the submaximal test was established by seven points: 65%, 70%, 75%, 80%, 85%, 90% \dot{\text{VO}}_{2}\text{max} intensity, and the 5.1 m\text{LO}_{2}\cdot\text{kg}^{-1}\cdot\text{min}^{-1} y-intercept (Russell et al., 2000). MAOD was calculated by integrating the difference between the actual and estimated oxygen uptakes (oxygen demand) from running speed extrapolation in the supramaximal test to the velocity–\dot{\text{VO}}_{2} regression of the submaximal test. The difference in bLa concentration before and after the supramaximal test was defined as the accumulated bLa concentration (\Delta bLa).

2.5. Statistical analyses

All statistical analyses were performed using SPSS version 22 (SPSS, Inc., Chicago, IL, USA). The relationship between two variables was investigated using the Pearson’s correlation coefficient. The multiple regression analysis was performed using a forced-entry method with 800-m velocity as an independent variable and physiological variables as dependent variables. Data are expressed as mean ± standard deviation and P < 0.05 is considered statistically significant.

3. Results

Table 1 presents the results of aerobic and anaerobic energy capacities. The
individual correlation coefficients of the velocity–VO$_2$ regression, calculated by seven points, demonstrated robust linearity (0.9981 ± 0.0022). In addition, vST was 23.2 ± 0.7 km·h$^{-1}$, corresponding to 90.7% ± 1.6% of the 800-m velocity, and the exertion time was 135.9 ± 11.0 s; all subjects ran for >2 min.

The 800-m velocity presented a significantly negative relationship with RE and MAOD ($r = -0.78$ and $-0.72$, respectively; $p < 0.05$; Figure 1) but not with VO$_2$max, LTI, and ΔbLa ($r = -0.16, -0.17$ and 0.11; $p = 0.61, 0.60$ and 0.72, respectively). In addition, RE demonstrated a significantly positive relationship with MAOD ($r = 0.91; p < 0.05$; Figure 2).

The multiple regression analysis revealed a significant positive relationship between the 800-m velocity and physiological variables, such as RE, LTI, and ΔbLa (adjusted $R^2 = 0.731$; $p < 0.05$; variance inflation factor [VIF] = 1.107, 1.078, and 1.086, respectively) as independent variables. The linear model of the 800-m velocity is as follows:

$$\text{800-m velocity (km·h}^{-1}) = -1.344 \times \text{RE (kcal·kg}^{-1}·\text{km}^{-1}) - 0.046 \times \text{LTI (%VO}_2\text{max}$$

$$+ 0.156 \times \Delta \text{bLa (mmol·L}^{-1}) + 34.046,$$

with standard error of 0.250 km·h$^{-1}$.

4. Discussion

The main finding of this study was the negative relationship of 800-m running performance with RE, the negative relationship with MAOD, and no significant relationship with VO$_2$max, LT, and ΔbLa.

Numerous studies reported RE as a physiological variable that is associated
with the long-distance running performance in well-trained runners (CV, <5.0%; Conley and Krahenbuhl, 1980; Morgan et al., 1989; Tanji et al., 2017a). Tanji et al. (2017a) suggested that runners in ≥1,500-m distance running events (1,500–10,000 m) experience a spurt phase near the end of the race, which may affect the success or failure of their performance. Similarly, the results of the present study are in agreement with those of Tanji et al. (2017b), indicating a relationship between the 800-m running performance and RE. Based on the perspective of previous studies (Conley and Krahenbul, 1980; Tanji et al., 2017), even well-trained 800-m runners (CV: <2.0%) possess superior comparable \( \dot{V}O_2 \text{max} \), suggesting that not \( \dot{V}O_2 \text{max} \) but the RE can elucidate the difference in the 800-m running performance. In particular, running at a high intensity recruits more type II muscle fibers, which are more likely to be less efficient than type I muscle fibers (Hunter et al., 2005). Assumedly, less recruitment of type II muscle fibers or adaptation to more efficient type II fibers results in an economical run at an even high intensity and, thus, high 800-m running performance. In addition, an 800-m running requires very high intensity, whereas \( \dot{V}O_2 \) during running reaches approximately 90% of \( \dot{V}O_2 \text{max} \) only (Draper and Wood, 2005; Sandals et al., 2006). Since the RE this study, which was evaluated at 90%\( \dot{V}O_2 \text{max} \), was closed with energy metabolism during an actual 800-m race, a possibility of a stronger correlation remains.

Both \( \dot{V}O_2 \text{max} \) and MAOD are considered as essential variables for the 800-m running performance (Nevill et al., 2008; Ramsbottom et al., 1994) because they are related to maximal velocity and contribute to the energy metabolism ratio. However, the results of the present study do not support the assertion described above. Perhaps,
this disagreement in results might be attributed to the difference in the performance of participants. In fact, all major studies that deduced relationships of the 800-m running performance were either conducted on male and female runners (CV, >10%, Nevill et al., 2008; Ramsbottom et al., 1994) or heterogeneous male runners (CV, >8%, Bosquet et al., 2007a; 2007b). However, the present study was conducted with only well-trained male homogeneous runners (CV, 1.9%). Although Ingham et al. (2008) demonstrated a relationship of the 800-m running performance and \( \dot{\text{VO}_2}\text{max} \) in highly-trained runners (CV, 2.2%), other studies (Craig and Morgan, 1998; Lacour et al., 1990b), including our study, did not observe any relationship between these variables in either well- or highly-trained runners (CV, 3.0% and 2.4%, respectively). Furthermore, owing to high \( \dot{\text{VO}_2}\text{max} \) in a majority of well-trained competitive distance runners (≥1,500-m events), no relationship between the running performance and \( \dot{\text{VO}_2}\text{max} \) has been established (Conley and Krahenbuhl, 1980; Tanji et al., 2017a). This study suggests similar results in well-trained 800-m runners.

Female runners have lower anaerobic energy metabolism capacity and running performance than those of male runners (Ramsbottom et al., 1997); thus, a significant relationship was observed between the 800-m running performance and MAOD when participants included both male and female runners. Furthermore, Olesen et al. (1994) evaluated that the mean MAOD of well-trained runners (average 800-m run times: 1′55”2; \( n = 8 \)) and recreational runners (average 800-m run times: 2′38”8; \( n = 6 \)) were 52.2 and 53.0 mLO\(_2\)·kg\(^{-1}\), respectively. These results suggest that male runners, regardless of the competition level, have MAOD of approximately 50 mLO\(_2\)·kg\(^{-1}\), and it is difficult to explain the difference in the 800-m running performance for male and/or...
homogeneous runners. On the other hand, the results of this study showed a significant negative relationship between MAOD and 800-m running performance ($r = -0.72$). However, MAOD was strongly related with RE ($r = -0.78$; Fig. 2), suggesting that higher anaerobic energy metabolism capacity leads to both lower 800-m running performance and RE. These results speculate that the ability to minimize the amount of energy metabolism at high-intensity running rather than producing anaerobic energy metabolism is strongly related to the 800-m running performance in well-trained runners, and that RE, but not MAOD, should be considered for evaluating the 800-m running performance. MAOD was evaluated by running for $>2$ min (135.9 ± 11.0 s) at \( \dot{V}O_2 \text{max} \) intensity of 121.7% ± 4.4%. In addition, the velocity-\( \dot{V}O_2 \) regression used for calculating the energy demand, comprised intensity at both below and above LT and demonstrated a strong linearity ($r = 0.9981 \pm 0.0022$), suggesting the high reliability of MAOD.

The findings of this study demonstrated that $>70\%$ of the 800-m running performance can be explained by RE, LTI, and \( \Delta bLa \), supporting our hypothesis that both aerobic and anaerobic energy metabolisms are required for considering the 800-m running performance. However, the low LTI capacity influencing the high running performance is a limitation of this model that warrants further investigation.

The assessment of MAOD requires at least two tests, and runners are required to put in efforts. In contrast, di Prampero and Ferretti (1999) suggested that AOD is estimated by \( \Delta bLa \) as multiplied $3.0 \text{ mL}O_2 \cdot \text{kg}^{-1} \cdot \text{mM}^{-1}$. Having a superior \( \Delta bLa \) capacity can sustain the running performance, even with increasing glycolytic pathway metabolism (Hasanli et al., 2015). Thus, \( \Delta bLa \) could be readily calculated by assessing
the accumulated blood lactate concentration during running and be useful to one of the anaerobic energy capacities. In addition, Lacour et al. (1990a) demonstrated a correlation between the 800-m running performance and ΔbLa in an 800-m race, which was consistent with the results of this study in which ΔbLa was evaluated by all-out running for 2–3 minutes, suggesting that ΔbLa evaluated by exhaustion exercise may correlate with the 800-m running performance. In particular, all-out running for 2–3 minutes nearly equates the exercise time and intensity as 800-m running, and ΔbLa has the potential to facilitate the estimation the 800-m running performance well. Thus, ΔbLa has some validity as an anaerobic parameter in the liner 800-m running performance model.

These results suggest that improving both RE and ΔbLa during training is necessary for well-trained 800-m runners. Apparently, enhanced RE positively affects the running performance of well-trained long-distance runners because they already possess a high VO₂max, improving which is reportedly challenging (Saunders et al., 2010). This study supports the application of the abovementioned theory in 800-m runners. Both high-intensity interval training and intermittent hypoxia training can be considered as effective training modules for improving both RE and ΔbLa (Midgley et al., 2007). Thus, it is essential for runners to undergo these training periodically. However, high VO₂max is a precondition for well-trained distance runners. Notably, training should not only focus on improving RE but also on maintaining VO₂max because it decreases when RE increases (TANJI and Nabekura, 2017).

5. Conclusion
This study investigated the correlation between the 800-m running performance and aerobic and anaerobic capacities in well-trained middle-distance runners (CV, <2.0% in 800-m running performance). The 800-m running performance correlated with RE, rather than VO₂max or MAOD, suggesting that the higher economical running was essential for the 800-m running performance among competitive 800-m runners. Moreover, the running performance >70% is explained by considering RE, LTI, and ΔbLa.

There are no conflicts of interest to declare.

Acknowledgments

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6. References


Tanji, F., Shirai, Y., Tsuji, T., Shimazu, W., and Nabekura, Y. (2017a) Relation between


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Table 1. Mean (± SD) values of aerobic and anaerobic energy metabolism capacities ($n = 12$).

Figures Legends

Figure 1. The relationships between RE (a) and MAOD (b) and the 800-m velocity ($n = 12$).

Figure 2. The relationship between RE and MAOD ($n = 12$).
Table 1. Mean (± SD) values of aerobic and anaerobic energy metabolism capacities (n = 12).

<table>
<thead>
<tr>
<th></th>
<th>( \dot{V}O_2\text{max} )</th>
<th>LTI</th>
<th>RE</th>
<th>MAOD</th>
<th>( \Delta bLa )</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>(mL·kg(^{-1})·min(^{-1}))</td>
<td>(%( \dot{V}O_2\text{max} ))</td>
<td>(J·kg(^{-1})·m(^{-1}))</td>
<td>(mLO(_2)·kg(^{-1}))</td>
<td>(mmol·L(^{-1}))</td>
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<tr>
<td></td>
<td>66.2 ± 4.9</td>
<td>80.4 ± 3.5</td>
<td>4.75 ± 0.33</td>
<td>57.0 ± 8.8</td>
<td>9.5 ± 0.9</td>
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Notes: \( \dot{V}O_2\text{max} \), maximal oxygen uptake; LTI, lactate threshold intensity; RE, running economy at 90% maximal oxygen uptake intensity; MAOD, maximal accumulated oxygen deficit; \( \Delta bLa \), maximal accumulated blood lactate.
$r = -0.78$
$p < 0.01$

$r = -0.72$
$p < 0.01$
$r = 0.91$

$p < 0.001$