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Physiological Determinants of Three-Kilometer Running Performance in Experienced Triathletes

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Abstract. Slattery, K.M., L.K. Wallace, A.J. Murphy, and A.J. Coutts. Physiological determinants of three-kilometer running performance in experienced triathletes. *J. Strength Cond. Res. 20(1):47–52. 2006.*—The present investigation examined the physiological parameters that contribute to 3-km running performance. Following 2 familiarization sessions, 16 experienced male triathletes ($\dot{V}O_2max = 55.7 \pm 4.9$ ml·kg^{-1}·min^{-1}, age = 31.3 ± 11.7 years) performed a 3-km time trial (3kmTT) and were assessed for selected physiological and anthropometrical characteristics. Stepwise multiple regression and correlation analysis was used to determine the variables that significantly related to 3kmTT. The analysis revealed that 82.3% of the adjusted variance in 3kmTT performance could be explained by peak treadmill running velocity during a $\dot{V}O_2$max test (Vmax) alone. The addition of the running velocity at lactate threshold (LT_{vel}) and peak lactate concentration ($[BLa^-]_{peak}$) to the prediction equation allowed for 93.6% of the adjusted variance in 3kmTT to be predicted ($Y = -13.64$ Vmax $- 25.61$ LT_{vel} $- 5.40$ $[BLa^-]_{peak} + 1358.5$). Correlation analysis revealed that Vmax ($r = -0.91$), LT_{vel} ($r = -0.90$), and $\dot{V}O_2$max ($r = -0.80$) were significantly related to running performance. These results show that Vmax was the single best predictor of 3-km running performance in experienced male triathletes and that both aerobic and anaerobic abilities are related to improved 3kmTT performance. Since the assessment of Vmax is relatively simple to implement, we suggest that determining Vmax may be a practical method for monitoring performance changes in short-term endurance running events.

Key Words. endurance, peak running velocity, lactate threshold

Introduction

Numerous physiological factors are related to running performance. Previous studies have shown maximal oxygen uptake, lactate threshold, running economy, body size, and muscular power to contribute to running performance over a range of distances (1, 11, 20–22, 24, 26). These results show that both aerobic and anaerobic characteristics are important for performance in endurance running.

Most studies have demonstrated a strong relationship between measures of aerobic fitness such as $\dot{V}O_2$max, lactate/ventilatory threshold, running economy, and endurance running performance (6–9, 11, 20–22, 31, 35). For example, Costill et al. (7) found an inverse correlation between athletes with a wide range of $\dot{V}O_2$max (54.8–81.6 ml·kg^{-1}·min^{-1}) and 10-mile run performance. Similarly, Grant et al. (11) reported a strong relationship between lactate threshold measured at a blood lactate concentration of 4 mmol·L^{-1} and 3-km running performance in trained middle- and long-distance runners ($r = 0.93$; $p < 0.05$). Furthermore, running economy has also been shown to strongly relate to endurance running performance (6, 24, 31). Collectively, these results demonstrate that increased aerobic fitness is related to improved endurance running performance.

A few recent studies have demonstrated the importance of increased anaerobic and neuromuscular capacities for improved endurance running performance (24–26, 28, 31). For example, Paavolainen et al. (24) reported that 5-km running performance was improved with increased leg power measured during a 5-bound jump test (5BT) and maximal velocity during a 20-m sprint in 10 endurance athletes through 9 weeks of explosive-type strength training. Similarly, Spurrs et al. (31) reported improved 3-km maximal run performance following 6 weeks of plyometric training that improved counter movement jump height, 5BT jump distance, and running economy in 17 male runners. These results suggest that improved neuromuscular abilities are related to increased endurance running performance.

The development of knowledge concerning the dominant physiological contributors that underlie short-distance running performance will enable greater specificity in training methods that will allow for improved competitive results. At present, there is no consensus on the best physiological contributors to relatively short-distance running performance. Therefore, this study was conducted to gain further insight into the physiological variables that affect running performance in experienced endurance athletes. The hypothesis for this study is that both measures of aerobic and anaerobic fitness will be important determinants of 3-km maximal run performance.

Methods

Experimental Approach to the Problem

A good understanding of the physiological determinants of athletic performance can be used as the basis for choosing appropriate tests for monitoring athletic ability and also for identifying factors that should be addressed in the construction of physical training programs. The aim of this study was to determine the relationship between various physiological variables and 3-km running performance. To achieve this, 16 experienced male triathletes were measured for physical characteristics, $\dot{V}O_2$max, running economy, lactate threshold, leg power, and peak treadmill running velocity during a $\dot{V}O_2$max test (Vmax). The subjects also completed a maximal 3-km time trial run (3kmTT) on a synthetic running track. To ensure accurate results, all subjects completed 2 familiarization sessions for each laboratory and performance test. Stepwise multiple regression was used to identify the strength of a predictor variable compared with other predictor variables so that important physiological variables could be identified and then suggested to be developed for improved 3kmTT. In addition, correlation analysis was used to establish the statistical relationship between the various physiological variables and 3kmTT performance.

Subjects

Sixteen experienced male triathletes ($\dot{V}O_2max = 55.7 \pm 4.9\ ml\cdot kg^{-1}\cdot min^{-1}$, age = 31.3 ± 11.7 years) volunteered to participate in this investigation. Ten of these subjects had competed at a national (Australian) and international level for their respective age groups. All subjects had regularly competed in triathlons for at least 3 years, performing more than 6 triathlons per year and training a minimum of 10 $h\cdot wk^{-1}$. The university ethics committee approved the study. The subjects were informed both verbally and in writing of the purpose and the potential risks and benefits of the study. All subjects gave written informed consent prior to the commencement of the research.

Procedures

The subjects were familiarized with the testing procedures by completing all laboratory physiological tests twice in the 6-week period prior to the commencement of the investigation. Each subject completed a standardized warm-up followed by a 3kmTT. Three days after the 3kmTT, anthropometric measures and selected physiological variables were assessed. All 3kmTT were completed at the same time of day (approximately 6:20 PM). The ambient temperature during the 3kmTT was 16°C and ~55% relative humidity.

This study was conducted at the end of the competition phase of the triathlon season and following a 2-week taper. Each subject had completed four 3kmTT during the previous 6 weeks, and no physical training was completed in the 24 hours prior to each testing occasion. All subjects were provided with written guidelines for diet and fluid consumption to ensure that their diet was standardized for the 24 hours prior to each testing session. These guidelines recommended that all subjects maintained a high carbohydrate intake and remained well hydrated prior to each test. Additionally, all attempts were made to provide standard encouragement for each subject during each test.

Warm-up. Prior to the 3kmTT, the subjects completed a standard warm-up that consisted of an 800-m run at ~60% maximum heart rate (HR max) on a synthetic track followed by three 100-m run efforts at ~70, 80, and 90% of maximum effort, respectively. Five minutes was then allowed for standard stretches to be completed.

Five-bound Test. Immediately following the warm-up, all subjects completed the 5BT. The 5BT required the subjects to stand with their preferred foot forward at the beginning of a tape measure and bound 5 consecutive times in an attempt to cover the greatest horizontal distance (24). The distance of the jump was measured from the beginning of the tape measure to the heel of the rear foot on the fifth jump. The subjects performed 3 trials, and the jump in which the greatest distance was covered was recorded. The reliability of this test for this group of athletes was determined to be good (technical error of measure [TEM] = 0.25 m or 2.3%; intraclass correlation coefficient [ICC] = 0.94).

Three-kilometer Time Trial. The 3kmTT required the subjects to run 3,000 m as a maximal time trial on a 400-m synthetic track. To minimize the effect of pacing and competition, the subjects began the 3kmTT 10 seconds apart with the fastest competitors commencing first. Throughout the 3kmTT the subjects were verbally encouraged to perform at their best. However, subjects were not advised of their lap splits. At the completion of the 3kmTT, the subjects performed another 800-m run at ~60% HRmax and self-selected stretches. The between-test reliability for the 3kmTT performance for this group of athletes was high (TEM = 9.2 s, TEM% = 1.4, ICC = 0.98).

Physiological Tests. Various physiological measures were taken during an incremental discontinuous run to exhaustion on a motorized treadmill (Star Trac, Unisen Inc. Irvine, CA). The test began with a 5-minute warm-up at 8 $km\cdot h^{-1}$. The protocol then commenced at a workload of 10 $km\cdot h^{-1}$, which was increased by 1.5 $km\cdot h^{-1}$ every 4 minutes until volitional fatigue. The subjects received a 1-minute rest period between workloads in which heart rate (Polar NV Heart Rate Monitor, Polar Electro Oy, Kempele, Finland) and blood lactate concentration $[BLa^-]$ (Accusport Portable Lactate Analyzer, Boehringer, Mannheim, Germany) were measured. Peak $[BLa^-]$ ($[BLa^-]_{peak}$) were taken immediately following the end stage of the maximal treadmill test. Maximal oxygen consumption ($\dot{V}O_2max$) was measured using the Physio-Dyne Gas Analysis System (Physio-Dyne Fitness Instrument Technologies, Quogue, NY), which was calibrated prior to each test with reference and calibration gases of known concentrations. The pneumotach was calibrated with ambient air using a 3-L syringe (Hans Rudolph, Inc., Kansas City, MO). The reliability of $\dot{V}O_2max$ measures for this laboratory were within the accepted range for exercise physiology testing laboratories (TEM = 1.5 $ml\cdot kg^{-1}\cdot min^{-1}$, TEM% = 3.1, ICC = 0.94). The reliability of $[BLa^-]_{peak}$ in this laboratory was determined to be low (TEM = 2.9 $mmol\cdot L^{-1}$, TEM% = 26.1%, ICC = 0.50).

Lactate threshold velocity (LT_{vel}) was calculated as the running velocity at a $[BLa^-]$ of 4 $mmol\cdot L^{-1}$ (32). Running economy ($RE_{14.5}$) was measured as relative oxygen uptake per minute at the running velocity corresponding to a running speed at 14.5 $km\cdot h^{-1}$ during the incremental treadmill test to exhaustion. The peak running velocity during the $\dot{V}O_2max$ test (Vmax) was determined as the highest treadmill speed maintained for a complete minute (22). In this study, all subjects reached Vmax at the lowest treadmill speed at which $\dot{V}O_2max$ was elicited (4). The intersession reliability of Vmax in this laboratory using this protocol was 0.4 $km\cdot h^{-1}$, or 2.4%, and the reliability of LT_{vel} was determined to be moderate (TEM = 1.0 $km\cdot h^{-1}$, TEM% = 2.7, ICC = 0.90).

Anthropometric Measures

Prior to the maximal treadmill test, anthropometric measures were taken by an accredited anthropometrist using standard methods of the International Society for the Advancement of Anthropometry and Kinanthropometry (ISAK). Body mass was measured using calibrated electronic scales (A+D Mercury, Adelaide, Australia) accurate to 10 g. Subjects were weighed postmicturition and dressed in minimal clothing. Each subject's body fat con-

TABLE 1. Physiological and performance variables of predictors of 3-km time trial (3kmTT) performance.

Variable	Mean ± *SD* (*N* = 16)	Range	Correlation with 3kmTT
3kmTT (min:s)	10:29 ± 0:59	9:08–12:01	
$\dot{V}O_2max$ (mL·kg^{-1}·min^{-1})	55.7 ± 4.9	47.7–65.7	−0.80*
LT_{vel} (km·h^{-1})	15.7 ± 1.5	13.0–18.1	−0.90*
RE (ml·kg^{-1}·min^{-1})	44.7 ± 3.2	38.8–54.9	−0.49
Vmax (km·h^{-1})	19.1 ± 1.4	17.5–21.0	−0.91*
$[BLa^-]_{peak}$ (mmol·L^{-1})	12.1 ± 2.7	5.4–16.1	−0.28
Body mass (kg)	74.6 ± 7.3	62.46–88.20	0.40
Σ9 skinfold (mm)	87.5 ± 24.3	47.2–125.6	0.27
Five-bound jump test m)	11.49 ± 1.05	10.18–13.39	−0.07

* Significant at $p < 0.05$.

TABLE 2. Partial correlations, standardized coefficients, and level of significance of predictors of 3-km time trial (3kmTT) performance.

	Vmax	LT_{vel}	$[BLa^-]_{peak}$
Partial correlations	−0.572	−0.822	−0.695
Standardized coefficient (β)	−0.320	−0.650	−0.246
Significance of standardized coefficients (*p*)	0.033*	0.001*	0.006*

* All correlations significant ($p < 0.05$).

tent was assessed using the sum of 9 skinfolds according to the protocol developed by Norton (23). Calipers accurate to 0.2 mm (British Indicators Ltd. St. Albans, London, UK) were used to measure each skinfold. The reliability of the skinfold measurements for this anthropometrist was high (TEM = 0.29 mm, TEM% = 1.9, ICC = 0.98).

Statistical Analyses

A stepwise multiple regression analysis using the linear regression model was used to determine a regression equation to estimate 3kmTT performance in experienced male triathletes ($N = 16$) using various physiological, anthropometrical, and performance parameters. Partial correlation coefficients were also calculated to assess the relationship between 3kmTT and the physiological and anthropometrical variables. Collinearity tolerance statistics were conducted to determine the correlation between the predictor variables. Any variable that had a tolerance level of <0.01 was not included in the model. For multiple regression analysis, it is recommended that there be between 5 and 40 subjects per predictor variable (5, 15, 33). In this study there were only approximately 5 subjects per determinant variable for the prediction equation, which is a low number for multivariate regression analyses. Accordingly, we suggest that the present results be interpreted in light of this limitation. Standard statistical methods were used for the calculation of means, standard deviation, and Pearson's product moment correlation coefficients. Statistical significance was set at $p \leq 0.05$. SPSS statistical software package (SPSS Inc., Chicago, IL) was used for all statistical calculations.

RESULTS

The performance, physiological, and anthropometrical characteristics of the subjects and their correlation to 3kmTT performance are shown in Table 1.

The stepwise multiple regression analysis revealed that 82.3% of the adjusted variance in 3kmTT performance could be explained by Vmax alone. The standard error of the estimate (SE_E) for this relationship was 24 seconds. The addition of LT_{vel} and $[BLa^-]_{peak}$ to the prediction equation allowed for 93.6% of the adjusted variance (94.9% unadjusted) in 3kmTT to be predicted ($Y = -13.64$ Vmax $- 25.61$ LT_{vel} $- 5.40$ $[BLa^-]_{peak}$ $+ 1{,}358.5$; adjusted $R^2 = 0.94$; $F_{3,12} = 74.5$, $p < 0.0001$). The addition of these variables to the prediction equation reduced the SE_E to 14 seconds. Partial correlations, standardized coefficients, and the level of significance of predictors of 3kmTT performance are shown in Table 2.

DISCUSSION

This study investigated the predictors of 3kmTT run performance in experienced triathletes. The main findings revealed that Vmax and LT_{vel} were two variables that could significantly predict 3kmTT performance. In addition, the physiological measures of Vmax, $\dot{V}O_2max$, and LT_{vel} were highly correlated with 3kmTT run performance. Notably, $RE_{14.5}$ and 5BT were not related to 3kmTT performance.

Vmax has been suggested to reflect the interaction between an individual's $\dot{V}O_2max$, exercise economy, anaerobic capacity, muscle power, and neuromuscular skill (14). These present data show that Vmax ($r = -0.91$) is the single best predictor of 3kmTT performance. This finding is in agreement with previous studies that have determined physiological predictors of endurance running performance in a variety of athletes. Many previous studies have shown Vmax to be associated with endurance performance over a large range of distances from 1500 m through to the marathon (11, 16, 17, 20, 22). For example, Lacour et al. (16) reported Vmax to be significantly related to the running performance of elite male distance runners during 1,500-m ($r = 0.62$), 3,000-m ($r = 0.64$), and 5,000-m ($r = 0.86$) track races. Additionally, Grant et al. (11) demonstrated that Vmax correlated strongly to 3,000-m track performance ($r = -0.86$) in well-trained middle- and long-distance runners. Furthermore, Noakes et al. (22) also reported strong correlations between Vmax and performance in 10-km ($r = -0.94$), 21.1-km ($r =$

−0.93), and 42.2-km ($r = -0.95$) road running races. Generally, the strongest relationships between Vmax and performance are observed with shorter distance events (i.e., <5,000 m; 7, 8). This is most likely due to the fact that Vmax more closely reflects the velocities at which these shorter distances are performed (8, 13), whereas race velocities in the longer-distance events are usually completed at speeds closer to lactate threshold (22). In agreement with these previous observations, the present results show that Vmax is an important physiological parameter for short-distance endurance running. Accordingly, we suggest that athletes who race over these distances should aim to increase their Vmax.

Previous studies have shown that Vmax is trainable and that increases in Vmax result in improved endurance performance (13). Furthermore, Vmax has previously been shown to be a sensitive and accurate marker of changes in endurance performance capacity. Increases in Vmax have been reported to occur both with and without concomitant improvements in $\dot{V}O_2$max, LT, and running economy (2, 13). This suggests that anaerobic capacity and neuromuscular characteristics are also important for improving Vmax in endurance athletes (3, 24, 26, 31). Since this measure can be influenced by many physiological factors that contribute to optimal endurance performance, we suggest the regular testing of Vmax may be a meaningful laboratory measure of performance for triathletes who complete run distances of <5 km. In addition, an advantage of using this test to monitor performance changes in triathletes is that it does not need expensive equipment that is required with blood lactate analysis or measurement of oxygen consumption.

The second physiological variable that was used in the prediction of 3-km run performance in the regression equation was the running velocity achieved at lactate threshold (LT_{vel}). This finding was expected as many previous studies have shown that submaximal exercise intensity markers such as lactate threshold are strong predictors of endurance performance and aerobic capacity (11, 21). In particular, LT_{vel} has been suggested as a good predictor of endurance running performance (9, 11, 21). In the present investigation, LT_{vel} was strongly correlated to 3kmTT performance ($r = -0.90$). These results are in accordance with Grant et al. (11) who observed a strong correlation between velocity at lactate threshold (4 $mmol \cdot L^{-1}$) and mean running velocity during a 3kmTT ($r = 0.93$) in 16 well-trained middle- and long-distance runners. LT_{vel} has also been reported to be a most sensitive and reliable measure for monitoring the training program of endurance runners. When taken with the present findings, we suggest that LT_{vel} may be useful for monitoring training progression in short-distance endurance running performance. Additionally, these results suggest that training programs for short-distance run performance, such as 3 km, should focus on improving LT_{vel} as well as Vmax.

Although $[BLa^-]_{peak}$ was not independently significantly correlated to 3kmTT, the addition of this variable to the Vmax and LT_{vel} data in the multiple regression equation reduced the unexplained variance from 11.4 to 6.4%. Furthermore, the addition of these variables to the multiple regression equation also reduced the SE_E from 24 to 14 seconds. Since $[BLa^-]_{peak}$ is often used as an indirect measure of anaerobic work capacity (12), we suggest that the regression results may be due to the anaerobic contribution to energy provision during the 3kmTT (27, 34). This result is not surprising since previous research has also shown that approximately 14% of energy contribution during 3kmTT is provided by anaerobic sources (27). In this study, multiple regression analysis was used to compare the importance of one physiological capacity over another in relation to 3kmTT performance. On this basis, the present results suggest that the focus of metabolic conditioning programs for athletes training for 3kmTT should be on increasing Vmax, LT_{vel}, and anaerobic work capacity.

The present results also show $\dot{V}O_2$max to be moderately related to 3kmTT performance in experienced triathletes. In spite of this, the addition of this physiological variable to the stepwise multiple regression did not appreciably increase the predictive strength of the equation. Previous investigators have also found $\dot{V}O_2$max to be both moderately and highly related to running performance (7, 9, 11). However, a high amount of variance has also been shown in the race performance of endurance athletes with homogenous $\dot{V}O_2$max values (6). For example, it has been shown that the correlation between $\dot{V}O_2$max and performance is relatively poor in a homogenous group of highly trained middle-distance runners (6). Therefore, we suggest that $\dot{V}O_2$max may not be the best physiological measure for the accurate prediction of performance in short-distance endurance events. In agreement, others have also reported $\dot{V}O_2$max to relate poorly with running performance in a group of triathletes with homogenous running ability and a high $\dot{V}O_2$max (29). Moreover, the $\dot{V}O_2$max of well-trained endurance athletes has been found to be relatively stable throughout a competitive season despite changes in performance (10, 14, 19). These findings suggest that $\dot{V}O_2$max may not be sensitive enough to determine transient improvements in performance and thus may not be a useful predictor of performance in well-trained endurance athletes. Therefore, physiological factors other than $\dot{V}O_2$max such as lactate threshold, running economy, muscular strength, power, muscle buffering capacity, and substrate utilization must also contribute to successful performance in endurance events (14).

In the present investigation, the 5BT was used to assess the neuromuscular contribution to 3-km running performance. Recent research has identified the importance of neuromuscular factors for improved endurance running performance (24–26, 28, 31). It has been hypothesized that an increase in the strength and power of the leg musculature may decrease the energy cost of running and therefore improve exercise economy and subsequent running performance (24, 31). However, although previous studies have shown changes in 5BT performance with plyometric training to relate to alterations in running economy (24, 31), to date no studies have shown a direct relationship between 5BT and endurance running performance. In agreement with these previous studies, the present results showed no significant correlation between the 5BT and 3kmTT performance.

The present results demonstrated no relationship between $RE_{14.5}$ and 3kmTT performance. This was an expected finding as others have suggested that the most meaningful measure of running economy should occur near race pace, rather than at an arbitrary submaximal velocity (1). Since 3kmTT is completed at an intensity around $\dot{V}O_2$max (8), we would expect a better relationship between variables measured at this intensity, rather than at submaximal values. This may explain why $RE_{14.5}$ was also not related to 3kmTT performance, but Vmax and $\dot{V}O_2$max were related to 3kmTT. Accordingly, in agreement with previous authors (1), we suggest that exercise economy measured at submaximal speeds may be more useful in the prediction of endurance running performance of greater distances.

PRACTICAL APPLICATIONS

The present findings are in accordance with the large amount of previous research that has shown Vmax to be related to running performance over a range of distances from 1,500 m to the marathon. In this study, Vmax was the best determinant of 3kmTT running performance in a group of experienced triathletes, suggesting that training should focus on methods to develop Vmax so that 3kmTT performances can be improved. In addition, the present results also show that increasing $\dot{V}O_2$max, LT_{vel}, and anaerobic contribution may also improve 3kmTT performance. Combined, these results suggest that both aerobic and anaerobic capacities are important for short-distance endurance events such as the 3kmTT.

Previous studies have recommended high-intensity interval training as a viable method for improving Vmax and lactate threshold (4, 18, 30). Specifically, these studies have shown that the greater amount of time an athlete can sustain $\dot{V}O_2$max, the greater the improvement in Vmax and subsequently running performance will be. We suggest that a well-structured and periodized training program should include sufficient focus on developing these capacities to improve short-distance running performance. Finally, since Vmax is relatively easy to measure and little elaborate equipment is required, we suggest that regular measurement of Vmax may be a practical low-cost method of assessing performance improvements in athletes who participate in short-duration endurance running events.

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