Physiological and Neuromuscular Variables Associated to Aerobic Performance in Endurance Runners: Effects of the Event Distance

CIÊNCIAS DO EXERCÍCIO E DO ESPORTE

Original Article

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ABSTRACT

The objective of this study was to analyze the validity of maximal oxygen uptake (VO2max), velocity corresponding to the maximal oxygen uptake (vVO2max), time to exhaustion in the vVO2max (Texh), anaerobic threshold (AT), running economy (RE), and explosive strength (ES) to predict performance in 1.500m, 5,000m, and 10,000m running events. Eleven moderately trained endurance runners (28.36 ± 6.47 years) participated in this study and performed: 10.000m, 5.000m, and 1.500m time trials on a 400m track; a maximal incremental load test to determine the VO2max, vVO2max, and AT; a submaximal and maximal constant load test to determine RE and Texh, respectively; and a vertical jump test to determine ES. The vVO2max alone accounted for 57% of variance in the 1.500m running performance. However, when the Texh, ES, and vVO2max were analyzed together, they were able to explain 88% of the performance. In the 5.000m running trial, Texh, vVO2max, and vAT responded for 88% of the performance ($p<0.05$). Differently, in the 10.000m time trial, the vAT was the only variable able to predict performance. In conclusion, the prediction of aerobic running performance based on VO2max, vVO2max, Texh, AT, RE, and ES is dependent on the running distance (1.500m, 5.000m, and 10.000m).

Keywords: prediction, time trial, running performance.

INTRODUCTION

Traditionally, the main variables which play an important correlation with endurance runners performance include maximum oxygen uptake (VO_{2max})(1,2), lactate threshold (LT)(2,3), anaerobic threshold (LAn)(3,4) and running economy (RE)(1,2,5). Nonetheless, trained runners may present similar values in these indices, and hence, other variables such as velocity associated to VO_{2max} (vVO_{2max}) and time to exhaustion in vVO_2max (Texh), may contribute to the success in predominantly aerobic events(2,4,6). The vVO_2max and Texh have shown important correlation with endurance performance in short and medium distance runs (800m to 5,000m). These events are predominantly dependent on the aerobic power, while in long distance events (> 5,000m) the aerobic capacity seems to be the most important aspect(4).

On the other hand, evidence on an important participation of the anaerobic metabolism in performance of trained runners in endurance events has been found(7). Additionally, Noakes(8) also suggests that besides the anaerobic participation in performance of these runners, aspects related to muscle power, which are directly integrated with the muscular contraction process regardless of the oxygen supply to the tissue, may limit endurance performance during competitions. Concerning the neuromuscular variables, the most highlighted in the literature are explosive strength (ES) and maximal strength (MS)(9-12).

Different studies have assessed aerobic performance prediction during running from the indices previously mentioned here. However, these studies used simple or multiple regression models assessing in the same group of athletes the correlations between the physiological and neuromuscular indices with aerobic performance in a single distance, which usually ranges between 1,500m and 10,000m(4). Moreover, it is possible to observe the lack of sufficient data in the literature on the event distance effects on the relation between physiological indices (VO_2max, vVO_2max, Texh, LAn and RE) and at least one neuromuscular index (ES) with aerobic performance (different distances) in moderately trained runners with homogeneous characteristics, highlighting the relevance of this investigation performance.

Therefore, it has been proposed that the distance of the event, and thus, the exercise intensity, may influence on the relations between physiological indices and aerobic performance(4). Nevertheless, studies which tried to relate aerobic performance obtained in the same athletes in different distances with two or more physiological and neuromuscular indices have not been found, especially using vVO_2max, Texh and ES. Thus, as the percentage of aerobic contribution (85% x 95%) and intensity related to vVO_2max (approximately 105% x 95%) are proportionally different between the 1,500m and 5,000m events, respectively(13), and, possibly in the 10,000m event, the hypothesis of this study is that the relations between physiological (VO_2max, vVO_2max, Texh, LAn and RE) and neuromuscular (ES) variables with performance in these distances may be different.

Therefore, the aims of this study were: 1) to analyze the prediction capacity of VO_2max, vVO_2max, Texh, LAn, RE and ES for performance in the 1,500m, 5,000m and 10,000m distances of moderately trained endurance runners; and 2) to assess the effects of the event distance in the relation between the physiological (VO_2max, vVO_2max, Texh, LAn and RE) and neuromuscular indices (ES) with aerobic performance in the 1,500m, 5,000m and 10,000m distances.

MATERIALS AND METHODS

Subjects

11 moderately trained runners (28.36 ± 6.47 years; 68.67 ± 8.05kg; 173.77 ± 7.23cm; and 10.62 ± 2.95% of body fat) participated in this study. All runners had had minimum of two years of experience with training and endurance events and in the period which preceded this study performance, had been training six days per week, with weekly volume which oscillated between 70 and 90km. This study was approved by the Ethics in Research with Humans Committee of the federal University of Santa Catarina (protocol # 336/06). The participants were informed on and familiarized with all experiment's procedures, as well as their risks and benefits, signing a free and clarified consent form.

Experimental protocols and procedures

The experimental protocol was conducted within a two-week period with all tests having been performed in the same period of the day. Initially, the athletes performed the performance simulated events on a 400-meter track, ordered in the 10,000m, 5,000m and 1,500m distances, respectively. On the following week, they initiated the laboratory tests for anthropometric measurement and determination of VO_2max, vVO_2max, LAn, RE, Texh and ES. All tests (laboratory conditions and field) were performed at similar weather situations (T = 23-25ºC and RHA = 60-68%) (Cosmed, Rome, Italy) and with a minimum interval of 48h between each of them.

Determination of running performance in 10,000m, 5,000m and 1,500m events

The runners performed simulated events on a 400-meter track on different days, in the 10,000m, 5,000m and 1,500m distances. Before each event, the athletes were allowed to perform a warm-up of moderate intensity followed by stretching.

Anthropometric evaluation

Body mass was measured on a scale with 0.1kg accuracy (Filizola®, São Paulo, Brazil). Stature was measured on a stadiometer with 0.1cm accuracy (Sanny, São Paulo, Brazil). Body fat percentage was estimated from the equation of three skinfolds (tricipital, abdominal, medium thigh) proposed by Evans *et al.*[14] for athletes, being used for measurement in an adipometer with 0.1mm accuracy (Cescorf, Porto Alegre, Brazil).

Determination of VO_{2max}, vVO_{2max} and LAn

The VO_2max was determined using an incremental protocol on treadmill (Imbramed Super ATL, Porto Alegre, Brazil). The initial velocity was 12km.h^{-1} (1% inclination), with increment of 1km.h^{-1} at every 3min until voluntary exhaustion. A 30s interval between each stage was set for collection of 25µl of blood from the earlobe for blood lactate dosage. Lactate analysis was performed with an electrochemical analyzer (YSI 2700 STAT, Yellow Springs, OH, USA). The VO_2 was measured breath after breath during the entire protocol from the expired gas (K4b^2, Cosmed, Rome, Italy), and the data were reduced to the mean of 15s. The VO_2max was considered asa the highest value obtained during the test in these 15s intervals. In order to consider that during the test the individuals had reached the VO_2max, the criteria proposed by Taylor *et al.*[15] and Lacour *et al.*[16] were adopted. The vVO_2max was considered as being the lowest running velocity, at which the VO_2max occurred[17,18]. The velocity referring to the LAn (vLAn) was found from the lactate concentration steady state of 3.5mmol.L^{-1}[19].

Determination of RE and Texh

Initially, the individuals performed a warm-up of 7min at 12km.h^{-1}, followed by rest of 3min. Subsequently, they ran for additional 8min at 14km.h^{-1}, with VO_2 being measured between the sixth and seventh min, from which the RE of the athlete was determined, which was defined as the relation between the VO_2 and the running velocity[5]. Subsequently, they rested fro 5min on the treadmill and the velocity was adjusted to 100% of vVO_2max and the individual was verbally stimulated to keep the effort until exhaustion. The VO_2 was also continuously measured during the entire protocol from the expired gas. The Texh was considered as the total exertion time kept in the vVO_2max and was expressed in seconds.

Determination of ES

The subjects performed a vertical jump protocol on a strength platform *Quattro Jump* (Kistler, model 9290AD) for determination of ES. The vertical jump technique with one preparation movement (counter-movement) in which the individual is allowed to perform the eccentric phase to perform the concentric phase of the movement next was used[20]. This jump has its application in the determination of the explosive strength level of the lower limbs[20-22]. All individuals performed a warm-up with 10-min duration, which was composed of stretching exercises and jumps, and later, performed three jumps on the strength platform with 1min of interval between each jump. Maximum height was considered from the Best jump obtained in the three trials permitted.

Data analysis

Data were expressed in mean ± standard deviation (SD). Data normality was verified by the Shapiro-Wilk test ($n < 50$). Correlation between time of the event in 1,500m, 5,000m and 10,000m and the VO_2max, vVO_2max, LAn, RE, Texh and ES was performed by multiple regression analysis using the *Stepwise* method. Analysis of variance one-way ANOVA, complemented by *post hoc* LSD test was used for comparison of the mean velocity in the events with vVO_2max and vLAn. In all analyses a significance level of 55 was adopted.

RESULTS

Performance times, physiological variables and ES variable are described in table 1.

The associations between vVO_2max and vLAn with mean velocity presented in each of the simulated events are expressed in table 2. According to the analysis of variance, mean velocity of the 1,500m event (v1,500m) did not present significant difference concerning vVO_2max. Regarding mean velocity kept during the 10,000m event (v10,000m), a v10.000m significantly higher than the vLAn was verified ($p < 0.01$).

Table 3 highlights the indices which presented prediction capacity in the different distances assessed. Therefore, it can be observed that the vVO_2max, when used in an isolated way, is able to explain 57% of the performance in the 1,500m event. Nevertheless, when the vVO_2max is used with the Texh and ES, these indices explain 88% of the performance in this event. In order to predict performance in the 5,000m event, the variables selected by the multiple regression analysis were the Texh, the vVO_2max and the vLAn ($R^2 = 0.88$, $p < 0.05$). In the 10,000m event, the vLAn was the only variable which presented performance prediction (30% of explanation).

Table 1. Mean ± SD and coefficient of variance (CV) of the indices determined in laboratory and on field.

Variables	Mean ± SD	CV (%)
VO_2max (ml.kg-1.min-1)	64.2 ± 5.4	8.4
vVO_2max (km.h-1)	18.4 ± 0.7	3.7
Texh (s)	344 ± 71	20.7
vLAn (km.h-1)	14.9 ± 0.7	4.6
VO_2LAn (ml.kg-1.min-1)	53.1 ± 4.9	8.2
RE (ml.kg-1.min-1)	50.4 ± 3.8	7.5
ES (cm)	41.7 ± 4.1	1.7
T 1,500m (s)	288 ± 12	4.2
T 5,000m (s)	1094 ± 48	4.4
T 10,000m (s)	2313 ± 91	3.9

VO_2max = oxygen maximal uptake; vVO_2max = velocity concerning the oxygen maximal uptake; Texh = time of sustaining at 100%vVO_2max; vLAn = velocity concerning the anaerobic threshold; VO_2LAn = oxygen uptake concerning the anaerobic threshold; RE = running economy; ES = explosive strength; T1,500m = time of the 1,500m event; T5,000m = time of the 5,000m event; T10,000m = time of the 10,000m event

Table 2. Correlation between vVO_2max and vLAn with performances in the different distances.

Variables	(km.h-1)	%vVO_2max	%vLAn
vVO_2max	18.4 ± 0.7	-	-
vLAn	14.9 ± 0.7	81.3 ± 5.4	-
v1.500m	18.8 ± 0.8	102.3 ± 2.7	126.3 ± 9.0
v5.000m	16.5 ± 0.7	89.8 ± 3.3	110.7 ± 6.6
v10.000m	15.6 ± 0.6	84.9 ± 3.9	104.6 ± 4.2

vVO_2max = velocity concerning the oxygen maximal uptake; vLAn = velocity concerning the anaerobic threshold; v1,500m = velocity concerning the 1,500m event; v5,000m = velocity concerning the 5,000m event; v10,000m = velocity concerning the 10,000m event.

Table 3. Coefficients of multiple correlation of the indices determined in laboratory with the time of the event in the 1,500m, 5,000m and 10,000m distances.

Distance	Variables	R^2
1.500m	vVO_2max	0.57
	vVO_2max + Tlim	0.70
	vVO_2max + Tlim + FE	0.88
5.000m	Tlim	0.41
	Tlim + vVO_2max	0.7
	Tlim + vVO_2max + vLAn	0.88
10.000m	vLAn	0.30

vVO_2max = velocity concerning oxygen maximal uptake; Texh = time of sustaining at 100%vVO_2max

DISCUSSION

The main result found in this study was that endurance performance prediction of moderately trained runners from variables of physiological (VO_2max, vVO_2max, Texh, LAn and RE) and neuromuscular characteristics (ES) is dependent on the event's distance (1,500m, 5,000m and 10,000m). However, despite the event duration presenting effects on the relation between these indices and performance of athletes in these distances, it is important to highlight that the aerobic system of energy production is predominant in all the studied events [13,23].

Some studies have assessed the capacity of physiological and neuromuscular variables in predicting performance of endurance runners[4,9-13,23-25]. Moreover, these studies have verified the influence of the event's distance concerning these variables and aerobic performance, since the percentages of contribution of the aerobic mechanism and intensities concerning the vVO_2max and vLAn are proportionally different between endurance events [4,9-13,23-25].

Although the VO_2max is considered an aerobic performance physiological determinant of endurance runners, when homogeneous groups of runners are analyzed, this variable has presented low performance discriminatory power in predominantly aerobic events[4]. Such aspect can also be identified in the present study, since there was not any correlation between events and this physiological index. One of the explanations for this behavior may be due to the low VO_2max variation coefficient (8.4%).

Furthermore, when runners who present similar performance and low VO_2max variability are assessed, difficulty in associating these variables can be found. Low variation coefficient for the values range of one or both variables (in this case, the performance times and VO_2max) determines a correlation coefficient close to zero when one variable is associated with the other. Since runners who present similar VO_2max values are assessed, it is believed that the group's homogeneity can provide more accurate information about the performance prediction capacity from the side of other physiological and neuromuscular variables (e.g.: vVO_2max and ES).

Interestingly, likewise the VO_2max, was the fact that the RE did not present correlation with any studied event. Such fact is quit surprising, since among homogeneous runners regarding their VO_2max values, the RE has been considered an important physiological variable in the determination of endurance performance[5]. However, in this study the RE also presented low variability (CV = 7.5%), finding hence, difficulty in associating the variables (performance x RE).

In the 1,500m distance, the vVO_2max, the Texh and the ES were the variables which presented significant correlation with the event, explaining 88% of the performance variation of the runners present in this study. Besides presenting correlation with the 1,500m, explaining 57% of performance when used in isolation, the vVO_2max did not present difference of v1,500m. In the studies by Lacour *et al.*[25] and Lacour *et al.*[16], significat correlation was found between the vVO_2max and performance of endurance runners in the 1,500m event ($r = -0.62$ and $r = -0.90$, respectively). Nonetheless, in the study by Lacour *et al.*[25] the sample was composed of a group of more homogeneous athletes (CV = 10% in v1,500m), while in the study by Lacour *et al.*[16] the runners assessed presented higher performance variation in the 1,500m (CV = 30% in the v1,500m). Such greater performance variation found in the study by Lacour *et al.*[16] may explain the high correlation presented between the vVO_2max and performance in the 1,500m. Moreover, the vVO_2max may better explain the performance differences among well-trained runners, being hence more reliable than other variables, such as VO_2max and RE[24].

In the study by Denadai *et al.*[4] it was observed that, in moderately trained endurance runners, the vVO_2max and Texh explained 88% of the performance variation in the 1,500m. Similar results were presented by Billat *et al.*[26], in which the vVO_2max and Texh were the variables which explained almost completely the performance variation of elite runners in the 1,500m event (95% of explanation).

Many studies have shown that, not only physiological variables, but neuromuscular ones as well, are also important to predict endurance performance[9-11]. Thus, one of the proposals of the present sutdy was to analyze the performance prediction capacity by physiological and neuromuscular variables, since in the model by Paavolainen *et al.*[9] running performance is influenced not only by the oxygen uptake and use, but also by factors concerned with the capacity in recruiting motor units and producing muscle strength. Some authors[27] have supported this idea, highlighting that in some studies which used the velocity peak in the maximal anaerobic running test (V_{MART}), which has been used to measure anaerobic capacity as well as muscle power, relation with the 1,500m event was found. Further studies[9-11] also support this Idea, since they present outcomes which associate neuromuscular characteristics with performance in 5,000m and 10,000m events. Such aspect stresses the importance of muscle power in endurance sports, since both the anaerobic component and the neuromuscular characteristics can play an important role in aerobic performance, especially when the athletes present similar aerobic features [9-11].

In the present study, the velocity kept during the 5,000m (~16.5km.h^{-1}) was higher than vLAn (~111%); however, it remained below the vVO_2max (~90%). The variables which explained performance in this distance were Texh, vVO_2max and vLAn (88% of explanation). Regarding the correlation found between performance in the 5,000m and Texh, which can be applied to obtain data on the lactic anaerobic capacity[28], the outcomes presented are similar to the ones previously highlighted in the literature[7], in which significant correlation was found ($r = -0.74$) between participation of the anaerobic component and performance in the 5,000m. The importance of the anaerobic capacity to endurance runners performance is hence highlighted, as in some other studies.

Analyzing performance in the 5,000m as well, Lacour *et al.*[25] found significant correlation ($r = 0.86$) between vVO_2max and mean velocity in this distance. Additionally, it has been found significant correlation ($r = -0.63$) between VO_2max demand and performance in the 5,000m distance[9]. In the study conducted by Paavolainen *et al.*[9], the maximum velocity reached in an incremental test during the treadmill running was calculated by the VO_2max demand; however, the treadmill inclination was increased (constant velocity) in the last stages of the test, being hence running performance on treadmill calculated not by the vVO_2max, but by the O_2 demand in the last minute before exhaustion (VO_2max demand), as proposed by the ACSM[29].

Tanaka *et al.*[30] verified the effects of endurance training (nine months) in the correlation between physiological variables and the 5,000m. The authors verified that, among the variables correlated with performance in the 5,000m event, the vVO_2max presented significant correlation before the training program ($r = -0.79$), during the training ($r = -0.75$) and after the training ($r = -0.67$)[30]. The study by Tanaka *et al.*[30] also found significant correlations between performance in the 5,000m and vLAn (coefficients of correlation between –0.79 and –0.83) for the same training periods mentioned above [30].

On the other hand, velocity in the 10,000m distance (~15.6km.h^{-1}) was significantly higher than in vLAn (~105%, $p < 0.01$) and close to 85% of vVO_2max. Concerning the studied variables, multiple regression analysis selected only the vLAn to explain performance in this event (30% of explanation). Tanaka *et al.*[30] also verified the effects of training on the relation of physiological variables and the 10,000m. Among the variables which presented correlation with performance in this study [30], the vLAn was also the best predictor presenting r values ranging between –0.81 and –0.84 with the time in this distance.

Similar results were found in the study by Morgan *et al.*[24] Who verified $r = -0.82$ between vLAn and performance in the 10,000m of well-trained runners. It is important to stress that, similarly to the present study, Morgan *et al.*[24] have assessed a group of runners with homogeneous characteristics of VO_2max (64.8 ± 2.1ml.kg^{-1}.min^{-1}; CV = 3.2%) and performance in the 10,000m (1.937 ± 76s; CV = 3.9%). Thus, in moderately trained runners, when the event distance determines intensity close to the vLAn, performance seems to be more dependent to aerobic capacity (blood lactate response) than to aerobic capacity or ES.

Nevertheless, according to the outcomes presented in this study, it can be concluded that aerobic performance prediction of moderately trained endurance runners, from the VO_2max, vVO_2max, Texh, RE, LAn and ES is dependent on the distance of the event assessed (1,500m, 5,000m and 10,000m). Similar studies with elite endurance runners should be conducted in order to verify the possible influences of these factors on performance of these athletes in different distances.

All authors have declared there is not any potential conflict of interests concerning this article.

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