Available online at www.sciencedirect.com
ScienceDirect
Science & Sports 22 (2007) 43–49
SCIENCE & SPORTS
http://france.elsevier.com/direct/SCISPO/

Original article

Average VO_2max as a function of running performances on different distances

VO_2max moyen en fonction de la performance de course sur différentes distances

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Received 31 August 2005; accepted 2 January 2006
Available online 18 December 2006

Abstract

Objective. – To determine the VO_2max differences as well as average VO_2max values for runners of both genders competing in various race distances at different performance level (International Amateur Athletic Federation (IAAF) scores).

Material and methods. – VO_2max of 137 males and 53 females top-class Spain runners was measured wit a multistage treadmill test. An exhaustive bibliographic analysis of the VO_2max values in different events was also done.

Results. – From Spain and literature data, VO_2max increases from 100 to 1500 m in runners with the same performance level (IAAF score). For the 3000, 5000, 10,000 m and marathon groups, VO_2max does not differ significantly. Furthermore and for the same event, small differences in performance level are associated with small or no differences in VO_2max.

Conclusions. – At the same level of performance (IAAF scores), VO_2max levels are increasing from 100 to 3000 m showing a greater importance of this parameter for training and selection purposes. On longer distances however, VO_2max levels are the highest but similar indicating that VO_2max is an important prerequisite but that VO_2max importance is similar for all distance events from 3000 m to marathon. On the other hand, within a distance event, VO_2max may be a good discriminator within a group of athletes showing a wide range of performances but not in a homogeneous group of elite athletes.

Résumé

Objectifs. – Déterminer les valeurs moyennes et les différences de VO_2max pour coureurs hommes et femmes de différents niveaux de performances (pointage IAAF) du 100 m au 42,2 km.

Matériel et méthodes. – VO_2max de 137 hommes et 53 femmes, élite des coureurs espagnols, fut mesuré lors d'un test progressif sur tapis roulant. Une analyse approfondie des données de la littérature fut aussi conduite.

Résultats. – Des données espagnoles et de la littérature, on constate que VO_2max augmente du 100 au 1500 m pour le même niveau de performance IAAF. Pour le 3, 5, 10 et 42,2 km, VO_2max ne diffère pas significativement. De plus, sur une même distance, de petites différences dans le niveau de performance ne sont associées qu'avec de petites ou aucune différences de VO_2max.

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doi:10.1016/j.scispo.2006.01.008

Conclusion. – Pour un même niveau de performance IAAF, VO_2max augmente du 100 au 3000 m démontrant une importance graduellement accrue de ce paramètre à des fins d'entraînement et de sélection. Sur distance plus longue cependant, VO_2max est encore plus élevé même s'il ne discrimine pas des coureurs élites homogènes, démontant quand même qu'il s'agit d'un prérequis important.

Keywords: VO_2max; Running performance; Events; Performance level; Gender

Mots clés : VO_2max ; Course à pied ; Performance, Genre

1. Introduction

A variety of physiological variables has been studied in order to determine the characteristics of athletes competing in different running distances. The maximal oxygen uptake has been the variable to which major attention has been paid. Therefore, the averaged VO_2max values, the relationship with running performance [13,19,20] and the contribution of the aerobic energy system in different events [15–17,56] have frequently been reported.

To the best of our knowledge however, only Mercier and Léger (1986) [40] attempted to study the differences in VO_2max between runners with the same level of performance in different distance events. In that study however, VO_2max was estimated by a maximal multistage running track test assuming same mechanical efficiency for all the subjects.

Thus the purpose of the present study was to determine the VO_2max differences as well as average VO_2max values for runners of both genders competing in various race distances at different performance levels using direct measurement of VO_2max. That was done on two set of data: our own and data from the literature.

2. Material and methods

A group of 137 male and 53 female runners training to compete at top-level running events was selected on the basis of their performances. The mean velocity achieved during their best season performance had to be included among the best 50 ever in the Spanish ranking (2002). The performances were obtained after consulting the official rankings published by the Statistics Department of the Real Federación Española de Atletismo. All runners have been training for more than 10 years and achieved national or international levels of competition (39 male and 17 female-trained runners have taken part in Olympic Games). The runners were also classified into groups in accordance with their best performance capability [5,55,64]. Subjects were chosen among sprint-trained runners (100 and 400 m), middle distance-trained runners (800, 1500, 3000 and 3000 m steeplechase) and long distance-trained runners (5000, 10,000 m and marathon) (Table 1).

The best performance of subjects involved in several events was established using Scoring Tables of the International Amateur Athletic Federation (IAAF) [57]. Using a database of performances obtained at world level, the IAAF Tables assign a definite score to each performance, enabling them to compare performances in different events for the same or different athletes.

Participants attended the National Center of Sports Medicine in Madrid, where the VO_2max values were measured during the maximal multistage test on a treadmill (Jaeger Laufergotest, model L6). All examinations were performed during the competitive season within 2 months of the runner's best performance. During this period, the athletes maintained their normal training program. The initial velocity and slope were 8 km h^{-1} and 1%, respectively. Thereafter, the velocity was increased by 2 km h^{-1} every 3-min stage. From the 7th (for male) and 6th stage (for female) the velocity was increased by 1 km h^{-1} every minute with a simultaneous increase in the slope of 2% min^{-1} up to a maximum of 5% until the subject reached voluntary exhaustion.

The VO_2 values were measured using a Jaeger EOS-Sprint spiroergometer. The VE was measured using a pneumotachograph that was specially designed to keep linearity at high volumes. The CO_2 exhaled was measured using an infrared ray analyzer and the O_2 by means of a paramagnetic system (both from Jaeger). VO_2max was chosen as the highest VO_2 value in the series of *30s-by-30s* VO_2 values.

Specific bibliographical analysis was carried out selecting only those studies showing the VO_2max values in athletes whose performance level was clearly pointed out. When many performances were reported for the same runner on different distances, only the best one was retained based on IAAF scoring tables.

Data were expressed as mean ± S.D. The coefficients of variance of performance (CV% = 100 × S.D./mean) were calculated. A multivariate linear model was done, with adjustment according to Bonferroni probabilities, using VO_2max, as dependent variables versus the type of event as independent variables. A P value of < 0.05 was considered indicative of statistical significance. The statistical analysis was performed with the Statistical Package for Social Sciences (Version 12.0).

3. Results

Both in male and female Spanish runners (Table 1), VO_2max values increase from 100 to 3000 m and stay similar for the longer distances (3000 m to 42 km). In males however, the difference between 100 and 400 m, is only significant for class A runners 100 m runners ($N = 9$) and 400 m runners ($N = 11$) (57.3 ± 4.7 vs. 61.7 ± 4.6 ml kg^{-1} min^{-1}, respectively).

Table 1
Descriptive statistics in male and female Spanish runners

	MALES				FEMALES				VO_2max
Event	Performance	VO_2max (ml.kg^{-1}.min^{-1})	Age (years)	n	Performance	VO_2max (ml.kg^{-1}.min^{-1})	Age (years)	n	Event differences (M + F) $p<0.05$
100 m	10.70 CV = 2.2%	61.9± 6.5	21.4	18	12.18 CV = 1.8%	48.2± 5.6	24.9	5	
400 m	47.77 CV = 2.1%	62.5± 6.2	23.9	22	55.23 CV = 4.2%	56.6± 4.4	22.3	9	
800 m	1:50.07 CV = 2.8%	68.5± 5.0	21.7	24	2:07.13 CV = 2.0%	63.4± 6.6	22.8	7	
1500 m	3:42.08 CV = 3.0%	73.9± 5.7	24.2	18	4:19.65 CV = 4.2%	61.7± 5.8	24.8	9	
3000 m	7:45.53 CV = 0.5%	77.6± 4.4	26.9	3	9:11.61 CV = 2.0%	69.2± 5.3	21.7	6	
3000 m steeplec	8:38.90 CV = 2.2%	79.9± 5.5	21.8	9					
5000 m	13:45.49 CV = 4.3%	78.9± 8.5	25.1	7	15:13.88 CV = 4.5%	69.8± 11.5	26.6	2	
10 km	28:58.75 CV = 3.3%	77.1± 5.6	26.1	17	33:54.77 CV = 3.1%	71.1± 8.3	24.6	5	
42 km	2:13:21 CV = 2.2%	80.1± 4.0	30.4	19	2:35:50 CV = 4.6%	73.7± 6.7	30.8	10	

CV = coefficient of variation in performance

In both genders, VO_2max values increased significantly (last column) from 100m to 3000 m but stayed similar thereafter. Values covered by the same vertical line are not significant. In males, difference between 100 m and 400 m runners are significant for class A runners only (57.3 vs. 66.5 ml.kg^{-1}.min^{-1}).

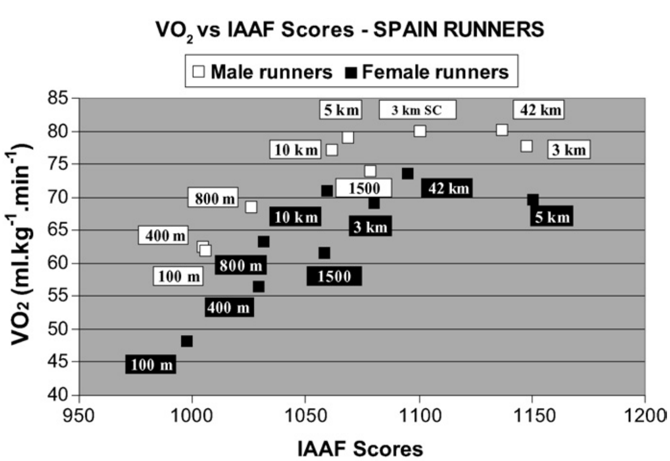

Fig. 1. Values of VO_2max as a function of IAAF scores for different distance events in male and female Spanish runners.

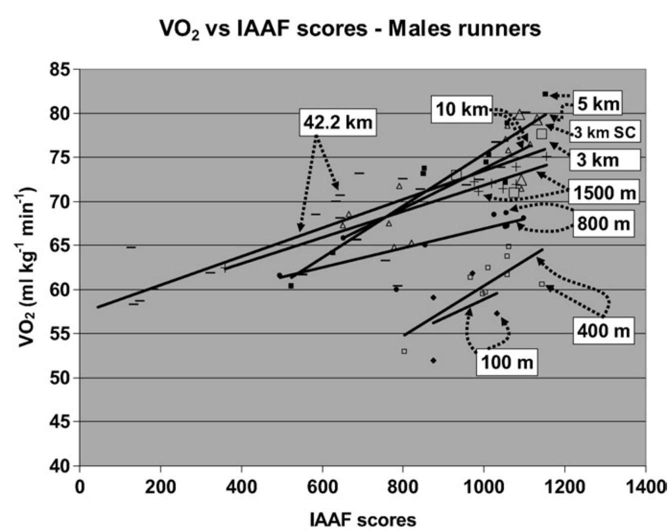

Fig. 2. Values of VO_2max as a function of IAAF scores for different distance events in male runners with values reported in the literature.

Nevertheless, in Spain, best performances are very good from 800 m to marathon but much lower in sprints events. In fact, the performance (measured as IAAF score) of sprint-trained runners was significantly inferior to performance of middle- and long distance-trained runners ($P<0.001$), which is a problem when comparing VO_2max of these runners (Fig. 1).

Thus in order to compare runners of the same levels on different distances, we have also drawn scatterplots and regressions of IAAF scores and VO_2max values reported in the literature (Fig. 2) for 100 m [22,26], 400 m [27,44,50,51,56,58], 800 m [13,22,26,31,50,56,58], 1500 m [4,18,31,32,47,58], 3000 m [7,31], 3000 m steeplechase [29], 5000 m [26,29–31, 45,50,52,58], 10,000 m [7,8,41,42,49,58,59,61,62] and marathon [3,10,12,19,21,23–26,43,48,50,53,54,58,59,65]. Due to the lack of data for 3000 m and 3000 m steeple, no regressions are drawn on these distances.

As with our original data, bibliographic analysis indicates that VO_2max increases progressively from 100 to 3000 m events in runners with the same levels of performance (IAAF scores). Fig. 2 also shows that VO_2max increases with the IAAF scores in almost all running specialities with somewhat high variability on each side of regressions lines however, remembering that points in Fig. 2 represent average values of different studies (different methodologies) and not individual data. For each distance event, Spanish male values of Fig. 1 superpose quite well with respective literature scatterplots and regressions of Fig. 2 (not illustrated).

From our Spanish data collected with the same methodology, we can make some practical VO_2max estimates for some levels of performance on different distance events (Table 2). For example, a 5000 m runner with an average running economy should have VO_2max between 79 and 82 ml kg^{-1} min^{-1} for performance ranging from 1070 to 1163 points (IAAF scores) or from 13 min 45 s and 13 min 18 s (Table 2).

In Fig. 3, we see the coefficients of determination between VO_2max and IAAF male scores for each distance event using average VO_2max and IAAF data from published studies as individual pairs of data as done in Fig. 2. On each distance, performance improves proportionally to VO_2max (Fig. 2), but the accuracy of the prediction is much lower in events shorter than 1500 m (Fig. 3). Nevertheless, this association was not found with our original data (Fig. 4).

With female runners, the comparison of our results with those obtained in other studies runners is presented in Fig. 5

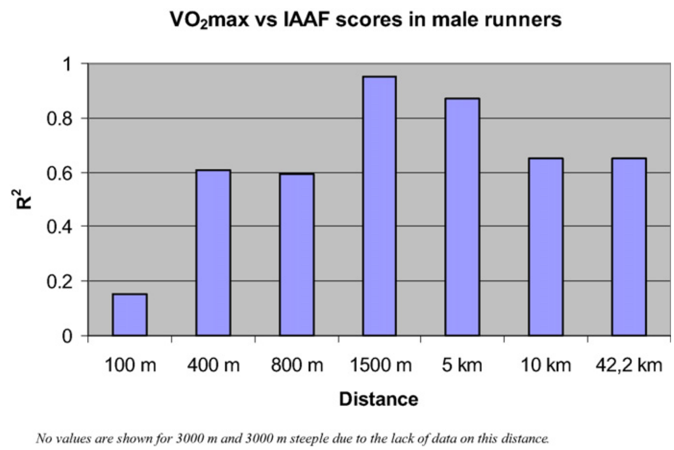

Fig. 3. Accuracy of the prediction of performance from VO_2max values with bibliographic data.

for 1500 m [18,32], 3000 m [46,63], 5000 m [52], 10,000 m [20,60] and marathon [6,12,24,25]. In female runners, the lack of sufficient studies does not permit a detailed regression analysis of results.

4. Discussion

This paper shows VO_2max values of male and female runners of different performance levels (IAAF scores) in different specialities from sprint to long distance events to give other researchers and coaches a valid reference to compare their athletes and a better understanding of VO_2max as a performance determinant.

Results of the present study showed that, in runners with the same performance level, the VO_2max increase progressively

Table 2
Average VO_2max according to different performance levels for some running distances (from Fig. 1)

		100 m	400 m	800 m	1500 m	5 km	10 km	42.2 km
WORST	IAAF scores				359	514-663		297-699
	Time				4:51	17:00-16:00		3:25-2:45
	VO_2max				62.5	60-64		58-64
	IAAF scores		772	508-894			649-883	761-893
	Time		52	2:12-1:55			34:00-31:00	2:40-2:30
	VO_2max		53	60-65			65-69	65-70
	IAAF scores					832-1020		
	Time					15:00-14:00		
	VO_2max					73-75		
BEST	IAAF scores	<1033	992-1137	1028-1099	977-1161	1070-1163	1060-1128	893-1111
	Time	>10.61	48.0-45.6	1:50-1:47	3:50-3:36	13:45-13:18	29:00-28:17	2:30-2:15
	VO_2max	>60	60-64	67-69	72-75	79-82	76-78	72-76

VO_2max in ml kg^{-1} min^{-1}.

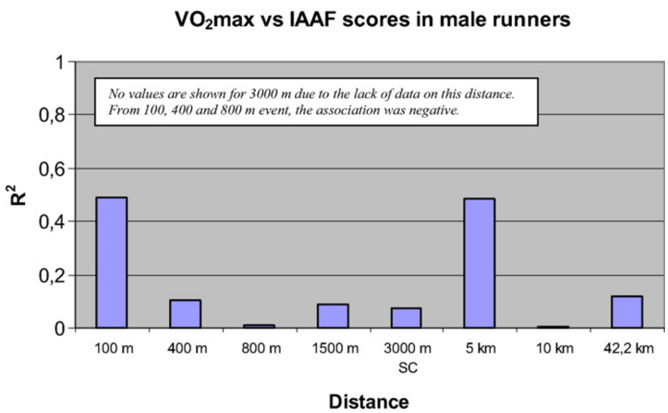

Fig. 4. Accuracy of the prediction of performance from VO_2max values with our original data.

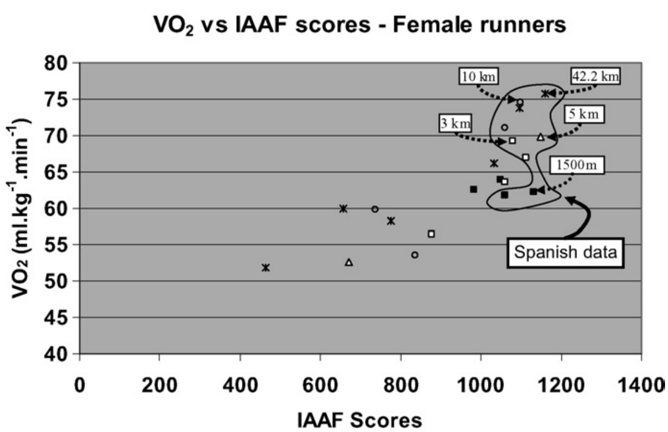

Fig. 5. Values of VO_2max as function of IAAF scores for different distance events in female runners using data from the literature and this study.

from 100 to 3000 m events. These findings can be consequent of contribution of aerobic energy system for these distances:

Of the energy for 400-m running, 40–50% is aerobic [16, 56] and the maximal oxygen uptake is reached at the end of the exercise [56], while the success in 100-m running is dependent exclusively of alactic and lactic anaerobic metabolism [17].

The energy for 800-m running is available in over 60–70% for the aerobic metabolism [16,56]. Nevertheless the success in 800 m running depends on an integrative contribution from aerobic and anaerobic systems [56]. Thus, a successful runner may be capable of running at a relatively rapid velocity while obtaining much of the necessary energy form the aerobic system, relying on a high VO_2max and conversely, other runners can obtained the same performance sustaining major contributions from the anaerobic system while having lower VO_2max.

Aerobic metabolism contributes the greatest part of energy for 1500-m running (77–86%) [15,56]. However, in agreement with Léger et al. (1985) [38], the race velocity on this distance is greater that the velocity at VO_2max, therefore the neuromuscular functions and anaerobic metabolism are more important for the success in this distance than in more longer events.

This study showed a similar VO_2max for runners competing in the 3000 m to the marathon events when the performance level is equivalent. In these events the contribution of the anaerobic metabolism is insignificant (< 10% in 3000 m) [15] and the velocity of competition is less than the velocity at VO_2max. Nevertheless a higher VO_2max is necessary in these distances to obtain greater velocity in competition from the same %VO_2max.

On the basis of the data contributed by another authors, we have established the average values of VO_2max to reach different elite level of performance in different distances. In general we can assume that among athlete's groups with relatively small performance differences (for example our original data), there is no significant VO_2max differences (ml kg^{-1} min^{-1}). But when we compare groups with significant performance differences (for example bibliographic data), there are also large differences in VO_2max values. This is conform to results found by others researchers: a significant relationship between VO_2max and running performance has been found in heterogeneous groups of athletes competing in different distances; nevertheless, VO_2max was found not to be a good predictor of performance in more homogeneous groups of runners in events including 800 m [13,31,63], 1500 m [32,63], 3000 m [46], 5000 m [29–31], 10,000 m [8,41,42,49] and marathon [1,12].

We also know from case studies [9,11,28,39] that VO_2max plateaus year after years of training in elite endurance athletes even though their performance continue to increase slightly due to other factors such as aerobic endurance, running economy or even anaerobic capacity on the shorter distances as discussed below.

The results of the longitudinal study by Legaz et al. (2005) [33] showed that the VO_2max remained unchanged after 3-years period of intense athletic conditioning and that the changes in running performance were not associated with the changes in VO_2max. On the other hand, it cannot be argued that VO_2max is unimportant.

In this study was showed that a different VO_2max value is necessary to success in different events and all endurance elite runners exhibited high VO_2max values. The current data suggest that a high VO_2max helped each subject gain membership in this elite performance cluster, but it did not discriminate success in homogeneous groups. Many studies on this topic in the last 20 years showed that others variables have been found to be of importance for the performance level, and that the VO_2max can be a poor predictor of performance capability in homogenous groups of runners: Since the early eighties, di Prampero et al. (1986) [14] have shown that in running, the maximal speed is set by the ratio between the subject's maximal metabolic power and the energy cost of running. In this way, Mercier and Léger (1986) [40] established higher associations ($r = 0.84–0.98$) between the maximal multistage running track [37] and running performance in distances of 600 m to marathon than those obtained for the VO_2max; they argued that the maximal multistage running track is a measure that encompasses the VO_2max and the mechanical efficiency. Others studies have highlighted the importance of another variable as, the kinetics of blood lactate accumulation during submaximal exercise [19], the running velocity at VO_2max and the time to exhaustion at 100% of velocity at VO_2max [2] and more recent parameters at rest as the skinfold thicknesses [35] and the left ventricular internal diameter at end diastole [34, 36].

From 400 m to marathon, performances are proportional to VO_2max but the accuracy of the prediction is much lower in events shorter than 1500 m. In fact, with our groups of homogeneous male sprinters (100, 400 and 800 m), the betters runners had lower VO_2max. The negative relationship observed for our data between $VO_{2\ peak}$ and 100 or 400 m running time is interesting. Nummela et al. [44] also reported a similar association between $VO_{2\ peak}$ and 400-m running time (range RT = 44.7–52.3 s, $r = 0.70$). This kind of exercise is essentially based on the exploitation of anaerobic energy sources. It is possible that in these studies, the poorer performing runners do not have the best physiological conditions to obtain an optimal performance of the anaerobic running system: maximal anaerobic power of neuromuscular units involved in sprinting, sprinting economy and anaerobic capacity [44], however, they are characterized by a relatively greater aerobic metabolism.

5. Conclusions

Differences in VO_2max of runners with the same level of performance (IAAF scores) on distances ranging from 100 to 3000 m clearly indicate a different contribution of VO_2max or aerobic requirement on these distances. From 3000 m to marathon however, average VO_2max is similar for runners with same performance level indicating similar importance of VO_2max for these events.

From 400 m to marathon, performances are proportional to VO_2max but the accuracy of the prediction is much lower in events shorter than 1500 m since speed and anaerobic capacity play and increasing role in the performance. For longer distances, the correlation is better but not perfect since performance also depends on running economy and endurance per se. Furthermore, when comparing data from different studies, variation between performance and VO_2max may also depend on the protocol and metabolic equipment used to assess VO_2max. Then, with homogeneous groups of runners, VO_2max alone generally fails to discriminate athlete's performances.

A future analysis with more data of VO_2max in relation with the running performance level, especially in female runners, is considered necessary to verify these conclusions.

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