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A review of the maximal oxygen uptake values necessary for different running performance levels

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ABSTRACT

It has been postulated that VO_2max is not a good predictor of running performance in homogeneous groups of runners and a plateauing of the VO_2max values has been documented in elite athletes. Nevertheless, elite endurance runners exhibit high VO_2max values, suggesting this helps them gain membership in the top performance cluster. Knowing the VO_2max values of groups of athletes is considered important for determining the maximum limit of performance of an athlete and an important aspect in the process of talent identification. One hundred and ninety top-class runners (137 males and 53 females) volunteered to participate in the study in which VO_2max was calculated by means of a progressive test on terdmills. Runners were classified into groups in accordance with their best performance capabilitie. Up to 1500m, an increment in VO_2max was observed and related to duration of the event. The VO_2max for elite athletes in the 3000m, 5000m, 10,000m and marathon groups did not differ significantly. Bibliographic analysis revealed small differences in VO_2max among groups with imilar performance levels and significant differences among groups that differ in performance.

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Introduction

Over the past two decades, coaches and sports scientists have shown keen interest in determining those physiological characteristics that allow distance runners to perform exhaustive exercise. Specifically, the coach and scientist have been concerned with optimising performance and the prediction of competitive success[1-3]. Maximal oxygen uptake

has been the physiological variable to which most attention has been paid[4-7]. Consequently, we have a great deal of information about averaged values in the different sport disciplines. However, we do not have the certainty of any study determining the values and differences of VO_2max among homogeneous groups of athletes competing over different distances and we could not find a review placing the levels neccesary for different performance levels at each distance.

The purpose of the present study was to determine the VO_2max differences in runners of both genders and to find the VO_2max values for groups of athletes competing in different distances in order to be able to examine the differences in this variable among athletes of different competitive performance levels.

Material and methods

Subject selection

A group of 137 male and 53 female runners training to compete in top-level running events was selected on the basis of their performances. The mean velocity achieved during their season's best performance had to be among among the best fifty ever in the Spanish rankings (2002). The performances were obtained after consulting the official rankings published by the Statistics Department of the Real Federación Española de Atletismo. All runners had been training for more than ten years and achieved national or international levels of competition (39 male and 17 female-trained runners had taken part in the Olympic Games).

The runners were also dichotomised into groups in accordance with their best performance capabilities[8-10]: Sprint trained (100m and 400m); middle-distance trained (800m, 1500m, 3000m and 3000m steeplechase) and long-distance trained (5000m, 10,000m and marathon) (Table 1). In each event the athletes were divided into "Class A", which comprised the half of the group with the best performances, and "Class B", which included the remaining athletes.

The criteria applied to determine the best performances of those athletes involved in several events was established by means of the corresponding performance equivalence according to the scoring tables published by the International Association of Athletics Federations (IAAF)[11]. The IAAF, using a database of performances obtained at world level, assigns a point score to each performance, enabling a comparison of different performances in different events.

Ergometric measurement

VO_2max values were determined at the National Centre of Sports Medicine in Spain. They were measured during a maximal aerobic power test on a treadmill (Jaeger Laufergotest, model L6), within the two months of the athlete's best performance. During this period, the athletes maintained their normal training programme. In the test the runners underwent a stepped protocol. The initial velocity and inclination were 8 km/h^{-1} and 1%, respectively. The velocity was increased by 2 km/h^{-1} after every 3 minute stage. From the 7th (for males) and 6th stages (for females) the velocity was increased by 1 km/h^{-1} every minute with a simultaneous increase in the slope of 2% per minute up to a maximum of 5% until the subject reached voluntary exhaustion.

The VO_2 values were measured using a Jaeger EOS-Sprint spiroergometer in conjunction with a Hellige Servomed oscilloscope. The VE was measured using a peumotachograph that was specially designed to keep linearity at high volumes. The CO_2 exhaled was measured using an infrared ray analyser 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 30sec-by-30sec VO_2 values.

Bibliographic review

Specific bibliographical analysis was carried out selecting only those studies showing the VO_2max values in athletes whose performance level was clearly pointed out. For all the studies we estimated the coefficient of variance of performance (CV). In the studies in which the authors did not show enough data in order to carry out this estimation, the range of performance was indicated. If there was a study in which the authors showed the individual performance of a runner in more than one event, the athletes were included in an event according to their highest IAAF Score.

Statistical Analysis

Data were expressed as mean±SD. The coefficient of variance of performance (CV%=100xSD/mean) was calculated. A multivariate linear model was made, with adjustment according to Bonferroni probabilities, using VO_2max as the dependent variable versus the type of event as the independent variable. A value $p<0.05$ was considered indicative of statistical significance. The statistical analysis was performed with the Statistical Package for Social Sciences (Version 12.0).

Results

Table I shows the descriptive statistic for each distance in relation to gender.

Significant differences of VO_2max among athletes from the 100m and 400m, were only observed in the female sample ($p<0.01$). However, a more detailed analysis in male athletes showed that the better

Table 1: Descriptive statistics in highly trained male and female runners

Event	Performance	VO_2max (ml/kg^{-1}/min^{-1})	Age (years)	N	Performance	VO2max (ml/kg^{-1}/min^{-1})	Age (years)	N
100m	10.70 CV = 2.2%	61.9 ± 6.5	21.4	1 8	12.18 CV = 1.8%	48.2 ± 5.6	24.9	5
400m	47.77 CV = 2.1%	62.5 ± 6.2	23.9	2 2	55.23 CV = 4.2%	56.6 ± 4.4	22.3	9
800m	1:50.07 CV = 2.8%	68.5 ± 5.0	21.7	2 4	2:07.13 CV = 2.0%	63.4 ± 6.6	22.8	7
1500m	3:42.08 CV = 3.0%	73.9 ± 5.7	24.2	1 8	4:19.65 CV = 4.2%	61.7 ± 5.8	24.8	9
3000m	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
3000m steeplechase	8:38.90 CV = 2.2%	79.9 ± 5.5	21.8	9				
5000m	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
10000m	28:58.75 CV = 3.3%	77.1 ± 5.6	26.1	1 7	33:54.77 CV = 3.1%	71.1 ± 8.3	24.6	5
Marathon	2:13:21 CV = 2.2%	80.1 ± 4.0	30.4	1 9	2:35:50 CV = 4.6%	73.7 ± 6.7	30.8	10

CV = coefficient of variation in performance

Table 2: VO_2max in male 100m and 400m runners

N	Performance	VO_2max (ml/kg^{-1}/min^{-1})	References
100m			
9	10.52 CV = 1.6%	57.3 ± 4	The current study "Class A" runners
18	10.7 CV = 2.2%	61.9 ± 6.5	The current study
7	11.00 CV = 1.0%	52 ± 2	[12]
7	11.00 CV = 5.5%	59.1 ± 2.3	[13]
400m			
9	45.6 CV = 1.3%	60.6 ± 3.2	[14]
9	45.6 CV = 1.3%	60.6 ± 3.2	[14]
11	46.92 CV = 1.1%	64.8 ± 4	[15]
11	46.97 CV = 0.8%	61.7 ± 4.6	The current study "Class A" runners
2	46.98 45.63-48.33	63.7	[16]
22	47.77 CV = 2.1%	62.5 ± 6.2	The current study
3	47.9 CV = 2.3%	59.7 ± 4.0	[17]
20	48.0 CV = 2.9%	59.5 ± 3.5	[14]
18	Range 44.7-52.3	61.4 ± 6.3	[18]
4	Range 50-53	53 ± 3	[19]

CV = coefficient of variation in performance

runners in the 100m (Class A, n = 9) had a lower VO_2max than the remaining athletes, 57.3 vs 66.5 ml/kg^{-1}/min^{-1}, respectively. Therefore, the better 100m runners showed lower VO_2max compared to the 400m runners ($p<0.001$).

The male 100m and 400m groups presented a lower VO_2max compared to middle-distance and long-distance runners ($p<0.001$). Similar results were found for the female samples. However, the significance levels were smaller due to the size of the samples.

In male 800m runners, the VO_2max was lower compared to 1500m, 3000m, 3000m steeplechase ($p<0.01$) and long-distance

Table 3: VO_2max in male 800m and 1500m runners

N	Performance	VO_2max (ml/kg^{-1}/min^{-1})	References
800m			
12	1:47.54 CV = 1.5%	68.1 ± 5.4	The current study "Class A" runners
5	1:48.99 CV = 2.9%	67.2 ± 3.5	[20]
14	1:49.1 CV = 1.7%	67.1 ± 3.4	[14]
6	Range 1:47.64-1:50.42	68.7	[16]
24	1:50.07 CV = 2.8%	68.5 ± 4.9	The current study
5	1:53-2:00	65 ± 2	[19]
7	1:59.4 CV = 0.4%	60 ± 3	[12]
11	2:05 CV = 3.8%	65.8 ± 1.4	[13]
11	2:12.6 CV = 5.5%	61.6 ± 5.1	[3]
1500m			
9	3:36.56 CV = 1.0%	75.1 ± 6.1	The current study "Class A" runners
5	Range 3:38.51 – 3:46.43	71.9	[16]
18	3:42.08 CV = 3.0%	73.9 ± 5.7	The current study
8	3:44.55 CV = 1.6%	71.5 ± 4.8	[21]
12	3.46.73 CV = 2.2%	72 ± 4.3	[20]
9	3:49.3 CV = 4.4%	71.2 ± 4.7	[22]
18	3:50.08 CV = 4.3%	72.2 ± 4.3	[23]
56	4:51 CV = 10.3%	62.5	[24]

CV = coefficient of variation in performance

Table 4: VO_2max in male 3000m and 3000m steeplechase runners

N	Performance	VO_2max (ml/kg^{-1}/min^{-1})	References
3000m			
3	7:45.53 CV = 0.5%	77.6 ± 4.4	The current study
9	7:57 CV = 2.9%	71.0 ± 5.3	[25]
5	8.10.84 CV = 2.3%	72.9 ± 4.7	[20]
3000m steeplechase			
4	8:29.15 CV = 1.3%	79.3 ± 3.4	The current study "Class A" runners
5	8:38 CV = 1.2%	72.4 ± 1.2	[6]
9	8:38.90 CV = 2.2%	79.9 ± 5.5	The current study

CV = coefficient of variation in performance

runners ($p<0.001$). The VO_2max of the male 1500m runners was lower compared to 3000m runners ($p<0.05$) and marathon runners ($p<0.001$). The female 800m and 1500m runners had lower VO_2max values compared to marathon runners ($p<0.001$). In both genders, the marathon runners presented the higher VO_2max values, however the 3000m, 3000m steeplechase, 5000m, 10,000m and marathon groups did not differ significantly.

The comparison of our results with those obtained in other studies is evidenced in Tables 2 to 8. The different studies are organised downwards according to the worst athlete´s performance.

Discussion

The involvement of the aerobic metabolism in energy production progressively increases from the 100m to 1500m and 3000m events. Therefore, it will be necessary for the VO_2max to increase at the same rate to achieve an equivalent performance. This supposition has been confirmed in the present study. Hence, if a athlete wants to cover a distance greater to the one appropiate for her/his physiological condition with an equivalent performance (being her/his VO_2max inferior) or keeping the same speed as a top-level athlete in that distance, he/she would have to produce energy anaerobically from the first seconds of the event. This would cause an excessively quick accumulation of lactate in the muscle and blood and consequently the need to reduce speed drastically before finishing the competition.

The involvement of the aerobic metabolism in energy production in the 3000m, 5000m, 10,000m and marathon does not differ significantly. Therefore, no significant differences in VO_2max should be expected among these athletes and, indeed, in this study, the VO_2max did not differ significantly between these groups.

Many researchers have attempted to explain how the variable VO_2max can account for a vast proportion of the variance in distance running performances. A significant relationship between VO_2max

Table 5: VO_2max in male 5000m and 10,000m runners

N	Performance	VO_2max (ml/kg^{-1}/min^{-1})	References
5000m			
3	13:18.22 CV = 0.5%	82.1 ± 4.7	The current study "Class A" runners
7	13:45.49 CV = 4.3%	78.9 ± 8.5	The current study
5	13:46.45 CV = 3.8%	72.1 ± 4.6	[20]
6	13:58.8 13:57.1 – 14:00.4	75.3	[16]
8	14:04.70 CV = 3.0%	74.4 ± 4.0	[14]
8	14:05 CV = 0.6%	74.4 ± 1.3	[6]
7	14:48 CV = 1.4%	73.7 ± 1.5	[13]
8	14:49.00 CV = 1.7%	73.1 ± 2.5	[26]
12	16:07 CV = 4.0%	64.1 ± 3.9	[27]
14	16:48 CV = 4.8%	60.4 ± 1.4	[28]
10000m			
9	28:17.81 CV = 1.8%	76.5 ± 5.9	The current study "Class A" runners
11	28:33 CV = 2.0%	71.5 ± 4.6	[25]
22	28:53.4 CV = 3.6%	75.8 ± 3.4	[29]
5	Range 28:36.6 – 29:21.0	78.6	[16]
17	28:58.75 CV = 3.3%	77.1 ± 5.6	The current study
10	31:43 CV = 5.6%	65.3 ± 4.9	[30]
12	32:06.00 CV = 3.1%	71.7 ± 2.8	[31]
10	32:17.4 CV = 3.9%	64.8 ± 2.1	[32]
20	32:27 CV = 3.1%	67.5 ± 3.9	[33]
9	33:47.13 CV = 1.5%	68.6 ± 0.7	[34]
21	34:06.6 CV = 5.9%	67.3 ± 5.2	[35]

CV = coefficient of variation in performance

Table 6: VO_2max in male marathon runners

N	Performance	VO_2max (ml/kg^{-1}/min^{-1})	References
10	2:10:56 CV = 1.3%	81.2 ± 3.9	The current study "Class A" runners
19	2:13:21 CV = 2.2%	80.1 ± 4	The current study
8	2:15	74.1	[36]
5	Range 2:12:07 – 2:21:04	73.86	[16]
5	2:17:05 CV = 1.7%	76.7 ± 0.7	[37]
12	2:21 < 2: 30	71.8 ± 1.2	[38]
4	2:23:42 CV = 4.0%	72.4 ± 2.3	[14]
6	2:27:23 CV = 5.8%	71.4 ± 4.2	[39]
13	2:29:59 CV = 6.5%	72.5 ± 3.8	[5]
9	2:30:42 CV = 5.4%	60.4 ± 6.5	[40]
10	2:32:31 CV = 5.4%	63.2 ± 2.9	[40]
12	2:36:37 CV = 6.2%	73.1 ± 5.2	[35]
16	2:37 2:30 – 3:00	65.6 ± 1.2	[38]
20	2:39:42 CV = 15.5%	68.1 ± 7.7	[7]
6	2:39:43 CV = 1.2%	70.7 ± 0.7	[41]
7	2:40:24 CV = 2.9%	70.0 ± 1.8	[13]
10	2:43:48 CV = 6.7%	68 ± 5.4	[42]
13	2:46:07 CV = 14.2%	61.7 ± 7.5	[1]
23	3:04:36 CV = 12.5%	61.9 ± 5.6	[43]
6	3:19:24 CV = 1.2%	60	[44]
7	3:24 > 3: 00	58.7 ± 1.9	[38]
46	3:26:00 CV = 12.9%	58.3 ± 7.3	[45]
25	3:26:54 CV = 17.5%	64.7 ± 9.0	[45]

CV = coefficient of variation in performance

Table 7: VO_2max in female middle-distance runners

N	Performance	VO_2max (ml/kg^{-1}/min^{-1})	References
1500m			
4	4:09.89 CV = 3.0%	62.2 ± 4.1	The current study "Class A" runners
9	4:19.65 CV = 4.2%	61.7 ± 5.8	The current study
6	4:20.72 CV = 5.3%	63.9 ± 4	[23]
8	4:29.4 CV = 4.3%	62.5 ± 3.7	[22]
3000m			
3	9:01.59 CV = 0.6%	66.9 ± 1.2	The current study "Class A" runners
6	9:11.61 CV = 2.0%	69.2 ± 5.3	The current study
10	9:17.93 CV = 3.7%	63.5 ± 5	[46]
16	10:14.96 CV = 4.7%	56.4 ± 4.4	[47]

CV = coefficient of variation in performance

and running performance has been found in heterogeneous groups of runners. However, different studies indicate that VO_2max is not a good predictor of performance in more homogeneous groups of runners (e.g. 50) and it has been reported that VO_2max does not relate to endurance performance within groups that are homogeneous in terms of VO_2max.

Nevertheless, the plateauing of maximal oxygen uptake in elite endurance athletes has been documented for many years in case studies only[51-54].

It cannot be argued from these data that VO_2max is unimportant. In this study, all endurance elite runners exhibited high values. The current data suggest that a high VO_2max helped each subject gain membership to this elite performance cluster. As the VO_2max values are predetermined genetically, it is unrealistic to hope for great increases due to training effects. Knowing the VO_2max values of groups of athletes on different levels of performance is considered important for determining the maximum performance limit of an athlete in relation to his/her VO_2max as well as an important point in the process of detection of sports accomplishments.

In the 100m, the lack of sufficient studies and the data obtained in our study do not allow us to reach definitive conclusions. Nevertheless we can deduce that the best athletes of this event achieve a VO_2max average < 60 ml/kg^{-1}/min^{-1}, being in accordance with data obtained from a study of athletes who achieved a performance better than 10.55 and a VO_2max of 57±6 ml/kg-1/min^{-1}. The 400m athletes with performances between 45.6 and 47.8 do not vary substantially with VO_2max

Table 8: VO_2max in female long-distance runners

N	Performance	VO_2max (ml/kg^{-1}/min^{-1})	References
5000m			
2	15:13.88 CV = 4.5%	69.8 ± 11.5	The current study
9	19:54 CV = 7.0%	52.6 ± 0.9	[28]
10000m			
3	33:09.60 CV = 0.6%	74.6 ± 5.7	The current study "Class A" runners
5	33:54.77 CV = 3.1%	71.1 ± 8.3	The current study
30	38:26.7 CV = 6.8%	53.5 ± 3.6	[48]
13	40:42.79 CV = 9.1%	59.7 ± 5.3	[2]
Marathon			
5	2:29:42 CV = 1.87%	75.8 ± 6.4	The current study "Class A" runners
10	2:35:50 CV = 4.6%	73.7 ± 6.7	The current study
6	2:41:51 CV = 1.2%	66.1 ± 1.4	[41]
9	3:07:57 CV = 6.3%	58.2 ± 4.8	[5]
6	3:21:48 CV = 0.9%	60	[44]
13	3:47	51.8 ± 3.2	[49]
10	4:42	45.8 ± 5	[49]

CV = coefficient of variation in performance

values being between 61-64 ml/kg^{-1}/min^{-1}. For those with a best performance over 48.0, the VO_2max value is slightly inferior to 60 ml/kg^{-1}/min^{-1}.

In the 800m, athletes with a best performance between 1:47.5 and 1:50.0 had a VO_2max average of 68 ml/kg^{-1}/min^{-1}. For athletes with a best performance close to or more than 2:00.0 the values are considerably lower.

The 1500m athletes with performances between 3:36.0 and 3:50.0 have VO_2max values that average between 72 and 75 ml/kg^{-1}/min^{-1}. In athletes with inferior performances, the values decrease considerably.

For the 3000m and 3000m steeplechase, due to the low number of studies, conclusions cannot be reached.

In the 5000m, athletes with a performance inferior to 13:30.0 achieve an average VO_2max value close to 80 ml/kg^{-1}/min^{-1}. For performances between 14:00 and 15:00, the values were between 73 and 75 ml/kg^{-1}/min^{-1}, disminishing considerably for performances above 16:00.

In the 10,000m, athletes with a best performance between 28:17 and 29:00 had VO_2max values between 76 and 78 ml/kg^{-1}/min^{-1}. For a clearly inferior performance (31:30), the average VO_2max is inferior to 70 ml/kg^{-1}/min^{-1}.

The performance level of our marathon runners was superior to those observed in the rest of the studies and the VO_2max found was clearly higher. In marathon runners with a performance between 2:16:00 and 2:30:00, the VO_2max is between 72 and 76 ml/kg^{-1}/min^{-1}. For performances of more than 2:30:00, the average VO_2max value is inferior to 70 ml/kg^{-1}/min^{-1}.

In general, we can assume that among groups of athletes with relatively small performance differences, there will not be significant differences in VO_2max (ml/kg^{-1}/min^{-1}), but there will be when groups with significant performance differences are compared.

Studies described the VO_2max (ml/kg-^{1}/min^{-1}) of different top-level athletes and the performance in competition[55,56]. These authors studied seven female middle-distance runners (four were top-level 1500m runners - avg time 4:07.9 (CV = 1.11%), one a 3000m runner - 10:03, one a 3000m and 5000m runner - 8:48, 15:22 and one a 5000m runner - 15:25). They also evaluated nine top-level long-distance runners (five 10,000m runners - avg time 32:47.2 (CV = 1.26%) and four marathon runners – avg time 2:31:17 (CV = 1.7%) and 14 "good" runners (11 of them ran their first 10,000m in an average of 38:37 with a range of 36:10 to 41:52) and 3 marathon runners whose performances were not reported. The VO_2max for middle distance runners was 68 ± 3.7 ml/kg^{-1}/min^{-1}, for long distance runners 66.4±4.5 ml/kg^{-1}/min^{-1} and for "good" runners 58.6±5.2 ml/kg^{-1}/min^{-1}. The results supplied by these authors corroborate that there are big VO_2max differences among athletes who differ significantly in their performance while, in turn, the differences among remarkable 1500m, 3000m and 5000m runners are not important when compared with long-distance athletes. The performance of the runners studied by these authors is generally slightly better than those in our study. However, their average VO_2max value is slightly lower than that of our athletes, corroborating that among athletes with a narrow scope in performance, the VO_2max is not a good performance predictor.

Similar to male athletes, in the few events with a sufficient number of studies, we found VO_2max differences only when there were significant performance differences.

Conclusions

This study has assessed the VO_2max in high-level runners and made an exhaustive bibliographic analysis with regard to the maximum limits of performance associated with VO_2max values. The results highlight the importance of evaluation of VO_2max to determine the maximum level of performance an athlete can be expected to achieve.

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