EXERCISE PHYSIOLOGY AND BIOMECHANICS

ORIGINAL ARTICLES

J SPORTS MED PHYS FITNESS 2009;49:358-63

Basic physiological measures determine fitness and are associated with running performance in elite young male and female Ethiopian runners

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Aim. **The aim of this study was to determine if possible, with the resources available in Ethiopia, to make significant associations between racing performance and laboratory physiological test results in elite young African runners.**
Methods. **Twenty-four young Ethiopian runners (12 males and 12 females) attended the physiology laboratory of the Addis Ababa University, where skin fold thickness, basic resting pulmonary function and heart rate (HR) during an incremental treadmill exercise test were recorded a week before or a week after two official 800 and 1 500 meter races. Performance was rated according to the scoring procedures of the International Association of Athletics Federations (IAAF): male runners (1 041, CV=4.1%), female (1 051, CV=2.8%).**
Results. **The sum of four skin folds was significantly correlated with male (r=-0.80, P<0.01) and female IAAF score (r= -0.78, P<0.01). IAAF score was also related to forced vital capacity (male: r=0.70, P<0.05; female: r=0.85, P<0.01) and forced expiratory volume in 1 s (male: r=0.63, P<0.05; female: r=0.80, P<0.01). For both sexes, HR at a fixed submaximal exercise workload was significantly associated with IAAF score. In both male and female runners, the more significant association was observed for a treadmill slope of 7.5% (r=-0.93, P<0.01; r= -0.95, P<0.01, respectively).**
Conclusion. **These results show that basic physiological measures are useful in measuring fitness and in predicting middle-distance running performance in a homogeneous group of elite young male and female Ethiopian runners.**

Key words: Skinfold thickness - Respiratory function tests - Heart rate - Running.

During the past two decades, the proportion of male Africans in the all time top 20 lists of middle- and long-distance running events (800 m to marathon) has increased from 26.6% [1] to 84.3% (International Association of Athletics Federations, IAAF, January 2008). In females, the equivalent average proportion of African achievements is only 28.6% (IAAF, January 2008). A similar effect is observed in junior runners (age≤19 years), where the proportions are 94.2% for males and 35% for females.

These data suggest that variations in the running performances of Africans can be partially due to sociological factors. At present, successful running is one of the best life choices in some African countries. In fact, many senior African runners live, train and compete in Europe, where they have an optimal training environment at their disposal.

The lesser economic development of women's athletics can explain the present-day differences between male and female African running performance. In fact, the average proportion of African youth runners (≤17 years) showing achievements in the 2007 top 20 lists is similar in males (30%) and females (27.5%). African youth runners live, train and compete in their home countries, and many African countries are poor with scarce technological development.

Received on September 15, 2008.
Accepted for publication on October 30, 2009.

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The scientific research on running performance is based on an increasing utilization of technological developments. In part, this fact proves to be contradictory because when the better runners of the world are young, they cannot benefit from the practical application of scientific studies.

The objective of this study was to determine if, with the resources available at the University of Addis Ababa, an association could be determined between resting and exercising physiological measurements and current race performance in elite young Ethiopian runners.

Materials and methods

Subjects

The participants in this study were 12 males (mean [SD] age 20.4 [2.6] years, body mass 62.7 [5.0] kg, height 1.78 [0.05] m, body mass index [BMI] 19.7 [0.9] kg/m^2) and 12 females (19.7 [2.9] years, 49.3 [4.7] kg, 1.67 [0.05] m, 17.8 [1.4] kg/m^2) Ethiopian runners who had engaged in intense athletic conditioning in order to compete at the top level in middle-distance events. All athletes trained six or seven days a week (20-25 hours) during the season.

We select the better runners until the coefficient of variation (CV) of the best performance, IAAF score [2] in the last season was <5%. Using a database of performances obtained at world level, the IAAF assigns a score to each performance. This enables the different performances in different events for the same athlete to be assessed and compared.

The participants provided written informed consent for the experimental procedures after the possible benefits and risks of participation were explained to them. The study protocol was approved by the the Research Ethics Committee of the Government of Aragón, Spain. The experiments were in accordance with the current laws of the country in which the experiments were performed.

Experimental design

Participants attended the physiology laboratory of the Addis Ababa University, Ethiopia where skin fold thickness, pulmonary profile and heart rate (HR) during an incremental treadmill exercise test were recorded. The subjects were instructed to arrive at the laboratory in a rested and fully hydrated state, at least 2 h post-prandial, and to avoid strenuous exercise in the 48 h preceding a test session. All tests were performed in the evening at the same time (±2 hours) with small variations in temperature (21±2.0 °C) and humidity (67.7±10%)

Subjects also completed at least an official 800 or 1 500 m running time trial on a 400 m outdoor synthetic running track within a week before or after the time of experimental testing: male 800 m race time (1.49.62, CV=1.59%, N.=10), male 1 500 m race time (3.44.94, CV=4.39%, N.=5), female 800 m race time (2.08.67, CV=1.61%, N.=11) and female 1 500 m race time (4.26.24, CV=2.10%, N.=7). An IAAF score was assigned for each race time.[2] In those athletes involved in the two events, only the best performance was included in the data analysis.

Procedures

Anthropometric measurements such as height (to the nearest to 0.1 cm) (Anthropometric Rod, GIANT, Germany), body mass (to the nearest to 0.1 kg) (Detecto-Medic balance) and BMI were recorded using standard procedures. Skin fold thicknesses at the biceps, triceps, subscapular and suprailiac were measured with a skin fold caliper (Holtain CO., UK) with ±0.2 mm accuracy, following previous guidelines.[3] Percentage body fat was calculated from skin fold measurements according to the equations of Durnin and Womersley.[4]

Basic resting pulmonary function was obtained by spirometric measurements (SpiroPro, Jaeger, Germany), following the standards of the American Thoracic Society.[5] The included measures were forced vital capacity (FVC), maximum inspiratory flow (PIF), maximum expiratory flow (PEF), forced expiratory volume in 1 s (FEV_1) (FEV_1%) and mid-expiratory flow rate (FEF 25-75%).

Finally, each runner performed an incremental treadmill exercise test (Runrace HC 1200, Italy) according to the Astrand Protocol.[6] The initial velocity and slope were 14 km·h^{-1} and 0%, respectively. Thereafter, the slope was increased by 2.5% every 2 min. The protocol was continued until the 6th (for male) and 5th (for female) stages. Prior to the test, the athletes performed a standardized warm up (3 min at 10 km·h^{-1}). HR was recorded during the last 15 s of each stage (Caser Marquette Electronics Inc., Milwaukee, WI, USA). All subjects were previously familiarized with the test protocol.

TABLE I.—*Descriptive statistics of variable measures.*

	Male	Female
Skin fold thickness		
Biceps (mm)	4.0 (0.7)[a]	5.0 (1.2)
Triceps (mm)	6.3 (1.0)[b]	8.4 (1.4)
Sub scapular (mm)	7.2 (0.7)	6.9 (1.0)
Suprailiac (mm)	5.7 (0.7)[b]	7.0 (1.2)
Sum of four skin folds (mm)	23.2 (2.2)[a]	27.3 (4.3)
% body fat	9.2 (1.3)[b]	18.2 (1.6)
Spirometric measurements		
FVC	5.4 (0.4)[a]	4.7 (0.8)
FEV_1	4.7 (0.4)[a]	4.1 (0.7)
FEV_1%	91.6 (5.2)	88.2 (6.9)
PEF	8.0 (0.8)[b]	6.9 (0.5)
FEF25-75%	6.3 (0.6)[b]	3.3 (0.5)
PIF	6.8 (0.8)[b]	5.1 (2.0)
Treadmill exercise		
HR at level 1 (S = 0%)	148 (12)	151 (18)
HR at level 2 (S=2.5%)	162 (8)	162 (13)
HR at level 3 (S=5.0%)	170 (5)	171 (12)
HR at level 4 (S=7.5%)	177 (7)	180 (10)
HR at level 5 (S=10%)	180 (7)a	190 (10)
HR at level 6 (S=12.5%)	182 (9)	

Data are means (± SD). FVC: forced vital capacity; FEV_1: forced expiratory volume in 1 s; PEF: maximum expiratory flow; FEF25-75%: mid-expiratory flow rate; PIF: maximum inspiratory flow; HR: heart rate; S: treadmill slope. [a]Significantly different for female (P<0.05); [b]Significantly different for female (P<0.01).

Statistical analysis

Statistical analysis was performed with the Statistical Package for Social Sciences (SPSS), version 14.0. Data are expressed as mean (SD). Student's t test and the U Mann Whitney test were used to compare measures between male and female runners. Pearson and Spearman analyses were applied to examine the relationships between the variables and IAAF score. Significance was set at P≤0.05.

Results

Table I shows the descriptive statistics of variables measures. The IAAF scores were similar for male (1 041, CV=4.1%) and female (1 051, CV=2.8%) runners. The male athletes were significantly taller and heavier (P<0.01), and possessed a lower sum of four skin folds (P<0.05) and body fat than the females (P<0.01). Except for FEV_1%, spirometric variables were significantly higher in males than in females (Table I). Male runners had a significantly lower HR than female runners only at level 5 (slope: 10%) (P<0.05).

The sum of four skin folds was significantly correlated with male (*r*=-0.80, P<0.01, Figure 1A) and female IAAF score (*r*=-0.78, P<0.01, Figure 1B). In male runners, the specific skin folds related to IAAF score were the sub scapular (*r*=-0.68, P<0.05) and suprailiac (*r*=-0.80, P<0.01), while in female runners it was the biceps (*r*=-0.77, P<0.01), subscapular (*r*=-0.64, P<0.05) and suprailiac (*r*=-0.75, P<0.05).

IAAF score was related to FVC (*r*=0.70) (Figure 2A) and FEV_1 (*r*=0.63) in the male runners (P<0.05). High correlations were also found in the female runners for FVC (*r*=0.85, P<0.01, Figure 2B) and FEV_1 (*r*=0.80, P<0.01). For both sexes, the remaining spirometric variables did not associate with running performance.

For both sexes, HR at a fixed submaximal exercise

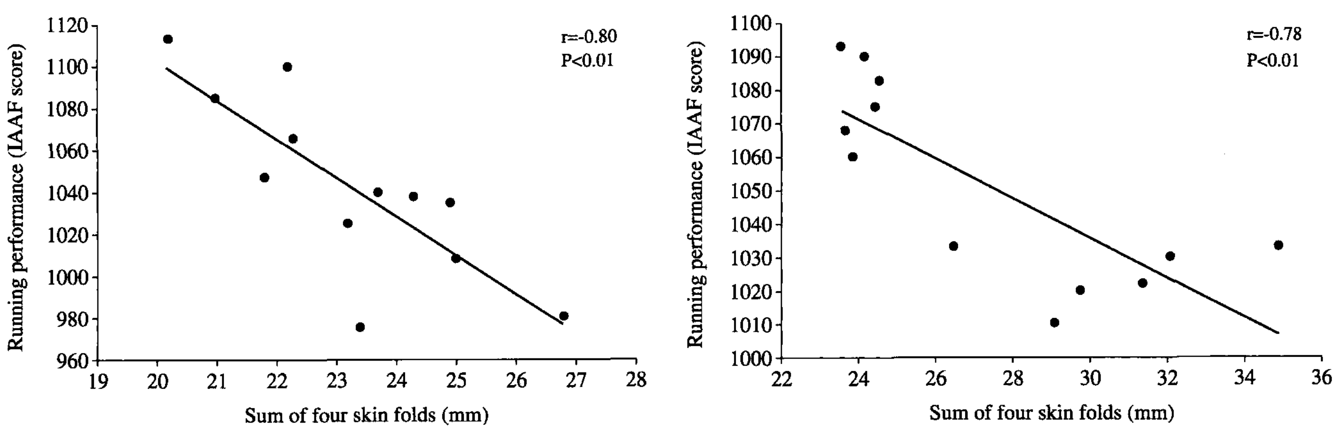

Figure 1.—Association between sum of four skin folds and IAAF score. A) Male runners; B) female runners.

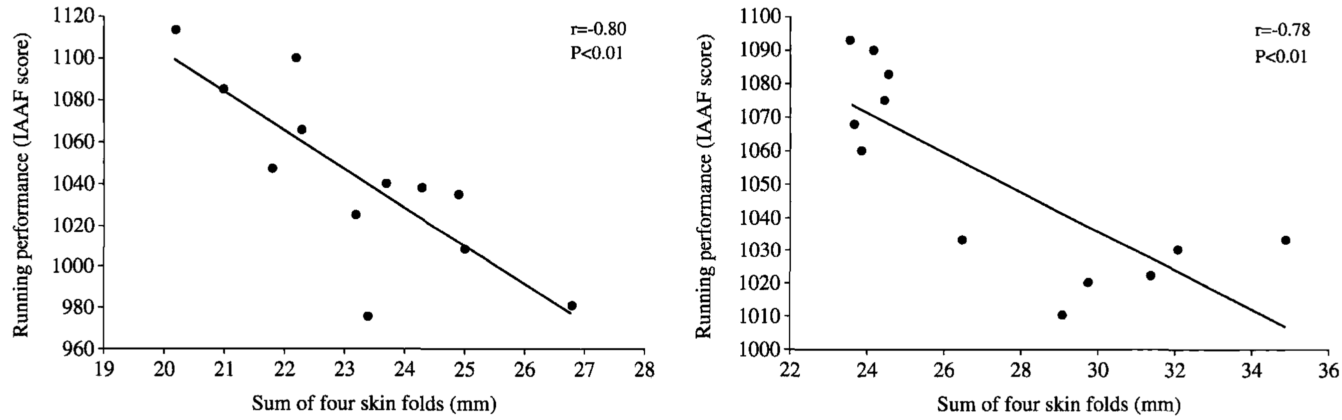

Figure 2.—Association between force vital capacity and IAAF score. A) Male runners; B) female runners.

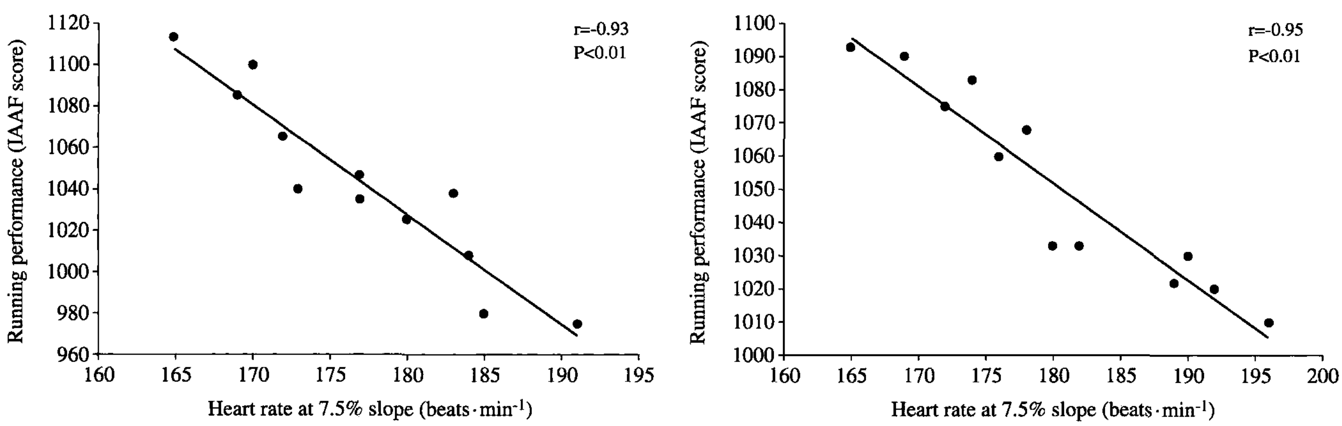

Figure 3.—Association between heart rate at 7.5% slope and IAAF score. A) Male runners; B) female runners.

workload was significantly associated with IAAF score. This was true in male runners for a range of the treadmill slope of 2.5 to 12.5% (r=-0.63 to -0.93), and in female runners for a range of 5% to 10% (r=-0.63 to -0.95). In both male and female runners, the more significant association was observed for a treadmill slope of 7.5% (P<0.01) (Figure 3A, B). The percentage of maximum HR (220-age) at the end of the incremental treadmill exercise test was 91.4±4.7% for male runners and 94.9±5.3% for female runners.

Discussion

Sport scientists and coaches both seek to know what variables determine the potential race performance. Runners turn to the physiology laboratory for information that helps determine their fitness status and guide the training. A variety of physiological variables have been found to be of importance for performance level in middle-distance running events. The majority of research relating physiological parameters to middle-distance running performance has dealt with well-trained males heterogeneous in performance (CV>5%) and with highly sophisticated methods.[7]

We perform a study with rather simple methods to show that is also possible in our world of highly sophisticated methods to present results applicable in daily training of these athletes. Specifically, this study demonstrates that simple measures of body, resting pulmonary function and HR at a fixed sub maximal exercise workload are related with middle-distance running performance in homogeneous groups of elite young male and female Ethiopian runners. Future studies must be performed to determine if these variables are also associated with the running performance of elite adult runners.

The sum of four skin folds of elite young male (23.2 mm) and female (27.3 mm) Ethiopian runners were comparable to those observed in elite Spanish middle-distance runners (male runners: 22.0 mm, female runners: 26.4 mm).[8] It is known that middle-distance running performance is enhanced with decreased skin fold thickness.[3] An excess of subcutaneous adipose tissue means a greater muscular effort to accelerate the legs, which, therefore, requires increased energy expenditure. In fact, the excellent running economy associated, at least partly, with anthropometric variables may be the common denominator in the success of black endurance runners of East African origin.[9] Nevertheless, very few studies have reported the relationship between body fat,[10] sum of skin folds (or specific skin folds) [11] and running performance in homogeneous groups of middle-distance runners. Kenney and Hodgson [10] reported no significant relationship between body fat and performance in a homogeneous group of elite 3 000 m steeplechase runners. Arrese and Serrano [11] found that only the skin fold thickness of the lower limbs is associated with 1 500 m race time. The authors did not find a relationship between skin fold thickness and running performance in the 800 m for men or in the 1 500 m race distance for women. In this study, the measurements of anthropometric variables were performed within two months of each best performance.

Decreased inspiratory and expiratory muscle strength, measured on the forced expiratory spirogram, have been reported after running [12] and are associated with lower performance.[13] Possibly, basal indices of pulmonary function can be associated with running performance. However, the evaluation of pulmonary function is not habitually reported in research with runners. In fact, in our knowledge, no one has yet reported the association between basal Spirometric measurements and running performance.

Submaximal variables are probably more associated with middle-distance running performance than maximal exercise variables.[14] At submaximal workloads, a higher HR has been associated with the additional oxygen cost and anaerobic energy resulting from more inefficient work.[15] A lower submaximal HR may be associated with the higher left ventricular internal diameter at end-diastole (LVIDd) found in better runners.[16] Higher LVIDd increases, in submaximal exercise, the capacity of the athlete to pump unusually large volumes of blood and oxygen to the muscles at a lower HR. This allows the muscles to achieve higher work rates before they outstrip the available oxygen supply, developing skeletal muscle anaerobiosis. Furthermore, a higher LVIDd can lead to a lower HR in processes such as the removal of products derived from metabolism and thermoregulation. However, previous research has paid little attention to the HR measured during an incremental treadmill test. To the author's knowledge, only three studies have reported the association between the HR measured during an incremental treadmill test and running performance.[15, 17, 18] The authors found high correlations between submaximal HR and the performance in a homogeneous group of marathon runners [15] and in heterogeneous groups of middle-and long-distance runners.[17, 18]

Although this study evaluates two of the more homogeneous groups investigated in the scientific literature,[7] in both sexes, we observed a very high correlation between the physiological variables and running performance. In addition, this association has been found for variables that it does not require sophisticated equipment to measure, and which are traditionally overlooked. It is possible that the high correlations found could be due to the elapsed time between the physiological tests and running performance (one week). In the majority of studies, the authors do not include this information, and in other research the elapsed time was too long.[19] This factor should be controlled in future studies.

In the present study, the runners performed an incremental treadmill exercise test based on a slope progression. Though a strong correlation was observed between the HR at a fixed submaximal exercise workload and running performance with this exercise protocol, a treadmill test based on a velocity progression and fixed incline (1% or 3%) would be more specific for track runners. Additionally, it would be interesting to determine the relationship among other easily measurable variables, such as the HR at sub maximal velocity and the peak treadmill velocity with running performance.

Variables associated with sports performance are easy to measure and do not need sophisticated methods; such variables are relevant for the process of selection of sports talents. In this way, further exploratory research on a broad range of sports, including the variables measured in this study, is suggested. Specifically, it would be beneficial to verify, in specific tests field where a greater number of subjects can be evaluated, if the HR at submaximal intensity is associated with the performance in different sports. In elite male marathon runners, a comparable correlation was recently observed for the race time between, HR, and lactate values measured at a sub maximal exercise intensity.[15] Accordingly, it would be interesting to measure in young athletes, the lactate concentration at a submaximal intensity to determine if this adds more information to the HR values.

In conclusion, the results of this study indicate that it is possible to determine the fitness of young Ethiopian runners and to find association with simple basic measurements and race performance respectively IAAF score.

Practical applications

Basic measures of body, resting pulmonary function and HR at a fixed submaximal exercise workload are not sufficient for a fine-tuning of individual training programs, particularly because they do not differentiate between aerobic and anaerobic performance capacities. Nevertheless, the results of this study show that these measures may be helpful during a first screening, especially in determining the fitness of elite runners in laboratories without sophisticated technological resources and for the selection of sports talents.

The results found in this study also suggest that the elapsed time between the physiological tests and race event can be determinant for predicting running performance, and therefore, this factor should be controlled and indicated in future studies.

References

1. Matthews P. World and Continental Records. In: Athletics'87. International Track and Field Annual. London: London and International Publishers Ltd, London and Simon and Schuster Ltd; 1987. p. 249-66.
2. Spiriev B. IAAF scoring tables of athletics. Monaco: IAAF; 1998.
3. Legaz A, Eston R. Changes in performance, skinfold thicknesses, and fat patterning after three years of intense athletic conditioning in high level runners. Br J Sports Med 2005;39:851-6.
4. Durnin JV, Womersley J. Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. Br J Nutr 1974;32:77-97.
5. American Thoracic Society. Medical Section of the American Lung Association. Standardization of spiromtery: 1994 update. Am J Respir Crit Care Med 1995;152:1107-36.
6. Astrand I. Aerobic work capacity in men and women with special referente toa ge. Acta Physiol Scand Suppl 1960;49:1-92.
7. Legaz-Arrese A, Munguía-Izquierdo D, Nuviala Nuviala A, Serveto-Galindo O, Moliner-Urdiales D, Reverter-Masia J. Average VO2max as a function of running performances on different distances. Sci Sports 2007;22:43-9.
8. Legaz Arrese A, González Badillo JJ, Serrano Ostáriz E. Differences in skinfold thicknesses and fat distribution among top-class runners. J Sports Med Phys Fitness 2005;45:512-7.
9. Lucia A, Esteve-Lanao J, Oliván J, Gómez-Gallego F, San Juan AF, Santiago C et al. Physiological characteristics of the best Eritrean runners-exceptional running economy. Appl Physiol Nutr Metab 2006;31:530-40.
10. Kenney WL, Hodgson JL. Variables predictive of performance in elite middle-distance runners. Br J Sports Med 1985;19:207-9.
11. Arrese AL, Ostariz ES. Skinfold thicknesses associated with distance running performance in highly trained runners. J Sports Sci 2006;24:69-76.
12. O'Krov JA, Loy RA, Coast JR. Pulmonary function changes following exercise. Med Sci Sports Exerc 1992;24:1359-64.
13. Seedhouse EL, Walsh ML, Blaber AP. Heart rate, mean arterial blood pressure, and pulmonary function changes associated with an ultraendurance triathlon. Wilderness Environ Med 2006;17:240-5.
14. Jones AM. A five year physiological case study of an Olympic runner. Br J Sports Med 1998;32:39-43.
15. Legaz Arrese A, Munguía Izquierdo D, Serveto Galindo JR. Physiological measures associated with marathon running performance in high-level male and female homogeneous groups. Int J Sports Med 2006;27:289-95.
16. Legaz-Arrese A, González-Carretero M, Lacambra-Blasco I. Adaptation of left ventricular morphology to long-term training in sprint- and endurance-trained elite runners. Eur J Appl Physiol 2006;96:740-6.
17. Costill DL. Thomason H, Roberts E. Fractional utilization of the aerobic capacity during distance running. Med Sci Sports 1973;5:248-52.
18. Pate RR, Sparling PB, Wilson GE, Cureton KJ, Miller BJ. Cardiorespiratory and metabolic responses to submaximal and maximal exercise in elite women distance runners. Int J Sports Med 1987;8(Suppl 2):S91-5.
19. Legaz Arrese A. Valoración fisiológica en deportistas de elite que compiten en distancias desde 100 metros hasta maratón: diferencias de sexo, pruebas y rendimiento [Tesis Doctoral]. Zaragoza: Universidad de Zaragoza; 2000.