Heliyon 9 (2023) e20842

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Normative reference and cut-offs values of maximal aerobic speed-20 m shuttle run test and maximal oxygen uptake for Tunisian adolescent (elite) soccer players

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A R T I C L E I N F O

Keywords:
Aerobic performance
BMI
HRmax
VO_2max
Percentile curves
Physical training
Prevalence
Practice period
Soccer payers

A B S T R A C T

This study aimed to develop reference curves of aerobic parameters of 20 m shuttle run test for Tunisian soccer players. The study was conducted in the 2022/2023 pre-season. The reference curves of the maximal aerobic speed (MAS) and the maximal oxygen uptake (VO_2max) were developed according to the Lambda, Mu and Sigma (LMS) method, using data from 742 Tunisian premier league soccer players aged 11–18 years. Measured variables included: weight, height, body mass index and maximal heart rate (HRmax). HRmax was measured when the participants completed the maximal aerobic speed. VO_2max was estimated using the 20 m shuttle run test protocol (speed increment every minute). Our results presented the smoothed percentiles (3rd, 10th, 25th, 50th, 75th, 90th and 97th) of MAS (km/h) and VO_2max (ml/kg•min^{-1}) according to age. In addition, raw data showed that VO_2 max was positively correlated with age ($r = 0.333$; $P < 0.001$), height (cm) ($r = 0.279$; $P < 0.001$), weight (kg) ($r = 0.266$; $P < 0.001$), practice period (years) ($r = 0.324$; $P < 0.001$) and BMI (kg/m^2) ($r = 0.10$; $P < 0.05$). However, it was negatively correlated to HRmax (bpm) ($r = -0.247$; $P < 0.001$). Only the measurements within the age group [12–12.99] are significantly higher ($p < 0.001$; ES = 0.63) compared with the previous age group [11–11.99]. Finally, regarding prevalence, our findings showed that 15.5 % of the players in our sample had VO_2max values above the 87.7th percentile cut-off, while only 0.3 % exceeded the 99.18th percentile. The development of normative curves could help coaches and physical

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https://doi.org/10.1016/j.heliyon.2023.e20842
Received 29 July 2023; Received in revised form 7 October 2023; Accepted 9 October 2023
Available online 10 October 2023

trainers to more accurately detect weaknesses in the aerobic performance of their players in order to sustain high-intensity repetitive actions during a soccer match.

1. Introduction

Soccer is considered one of the most popular sports in the world. It has a social and economic impact in many countries [1]. Because of this, professional soccer clubs always have a mission to develop talented and accomplished young professional players [2].This sport is based in a high intensity, intermittent sport, which involves changes of direction, jumps, sprints and tackles [3]. The performance of a player or team in this sport can be influenced by anaerobic capacity and aerobic metabolism which can provide up to 90 % of the total energy cost of a soccer match and depending on the players position [4].

Thus, the aerobic capacity is considerate as one of the most important factors influencing a soccer player's physical condition. As Van Winckel et al. [5] points out, developing this ability allows soccer players to cover distances effectively, typically about 9.1 km, including about 1.3 km at high running intensity. A recent systematic review found that female professional soccer players have high-speed runs ranging from 911 to 1063 m and sprint distances ranging from 223 to 307 m in official matches. However, male professional soccer players have running speeds ranging from 618 to 1001 m and sprint distances ranging from 153 to 295 m [6]. According to Strøyer et al. [7], in early puberty, maximal oxygen uptake (VO_2max) during soccer games can range from 50 to 64 ml/kg/min. These competitions typically involve a distance of about 6500 m, with about 670 m of high-intensity running and about 300 m of very high-intensity running [4,8]. Monitoring and assessment of players aerobic capacities can assist the coach to evaluate the effect of training practices and the overall training program, resulting in improved training prescription [9–11].VO_2max measurement, which refers to the body's maximal capacity to use oxygen for maximal effort is the common aerobic measurement method of the aerobic capacity [12,13]. Indeed, A high VO_2max is required to compete at the professional level in football. Thus a good VO_2max clearly indicates a good physical fitness of a soccer player and it can prevent or minimize the risks of injuries [14]. Several studies have been undertaken to analyze and understand the influence of growth, maturation and systematic training on the evolution of VO_2max at different ages during childhood and adolescence [15,16]. In adolescence, VO_2max is linked to body dimensions and the rhythm of biological maturation in athletes and non-athletes [17]. Given the importance of measuring VO_2max in classifying children's and adolescent's, it is necessary to establish VO_2max values according to age and gender [14].

In the perspective of screening growth, centile reference curves are commonly used technique to effectively monitor development across time. Routinely assessing the rhythm of growth and development, allows the identification of potentials concerns that may require early intervention [18]. Over the last decade, this tool has become an increasingly important methodological approach in many fields such as of pediatrics, physical education and sports sciences. This procedure facilitates the identification of participants who have a low fitness to set appropriate goals and promote positive health behaviors, or specific fitness features that may be considered important for athletic success [19,20].

In Tunisia, some percentile curves were constructed to monitor the anthropometric parameters of height, body weight and waist circumference [21–23]. Also recently curves of the maximal and resting heart rates of young footballers have been established [24]. However, to best our knowledge, there are no studies on normative values of the VO_2max of Tunisian footballers. Despite, these standards are necessary to track young football players. Therefore, the objective of this study is to develop the reference curves of VO_2max and maximal aerobic speed (MAS) of 20 m shuttle run test to screen the aerobic capacity of the Tunisian adolescent soccer players.

2. Materials and methods

2.1. Participants

The cross-sectional study was conducted in the 2022/2023 pre-season in the months of August and mid-September where the evening temperature varies between 25 C° and 33 C°. Seven hundred and forty-two male soccer's players (11–18 years) were recruited from nine teams (three teams from the capital, two teams from the north and northwest, and four teams from the central east) chosen using the random draw method and belonging to Tunisian premier league. The participants regularly participated in at least three training sessions per week and performing the Tunisian Football Federation competitions.

The participants and their parents were made aware of the nature, duration, and purpose of the experiment, as well as any potential inconveniences. The parents were also given informed consent indicating that their adolescents could leave the study at any time during the experiment without providing a justification.

The research was conducted in accordance with the Declaration of Helsinki (2013) and was fully approved by the Scientific and Ethics Committee of High Institute of Sports and Physical Education of Kef (06–2022).

2.2. Anthropometric parameters

Weight was measured with an electronic scale to the nearest 0.1 kg (HD-351; Tanita, Arlington Heights, Illinois, USA) and Height by portable stadiometer to the nearest 0.001 m (SECA Leicester, United Kingdom). Moreover, Body mass index (BMI) (kg/m^{-2}) was calculated as the ratio of body mass (kg) to square height (m^2).

2.3. The 20 m shuttle run test protocol

Before accomplishing the 20 m Shuttle run test, we caculate the pratice period (years) from the first day of training until the day of measurement.

In evening after school, all participants completed the progressive test once with soccer shoes between 17:00 and 20:00, exactly 24 h after their last training session. This test was conducted at the beginning of the training session on a synthetic or natural pitch. All the testing sessions were conducted at the same time of the day to minimize the effects of diurnal variation in the measured parameters [25–27].

During the test, participants run between two lines 20 m apart, following the rhythm of pre-recorded audio signals. The first sections of the test have been reserved as a warm-up phase due to the slower pace at the start. Concretely, the starting speed was set at 8.5 km/h, and it increased by 0.5 km/h every minute [28]. The test is ceased if the participant fails to reach the end lines two consecutive times or if the player reported fatigue. Maximal aerobic speed (MAS) and maximal heart rate (MHR) using Polar Team Sport System (Polar-Electro OY, Kempele, Finland) results were recorded at the nearest completed stage.

2.4. Estimated VO_2 max

The predicted VO_2max (ml/kg•min^{-1}) was obtained from by 20 m shuttle run test using the following regressions [28]:

For 6–18 years:

$$VO_2\ max = 31.025\ x\ MAS\ (km/h) - 3.248\ x\ Age\ (years) + 0.1536\ x\ MAS(km/h)\ x\ Age\ (years)$$

Over 18 years of age:

$$VO2\ max = -27.4 + 6.0\ x\ MAS\ (km/h)$$

With MAS = Maximal aerobic speed.

2.5. Thresholds for classification player levels

We identify VO_2max cut-off values can be used to categorize players who possess the physiological attributes required for professional soccer achievement or who have extreme aerobic capacity.

Two thresholds were applied using the references as follow:

VO_2max <60 (ml/kg•min^{-1}): a threshold below which an individual player is unlikely to possess the physiological attributes of success in the game professional soccer [29].

VO_2max >70 (ml/kg•min^{-1}): professional soccer development can reach this high value of VO_2max and exceed the current level of fitness [30,31].

2.6. Smoothed percentile curves

The percentile curves of the variables as a function of the age covariate stratified by biological sex were calculated using the LMS method [32]. This method transforms the distribution of raw data at each age into three smooth curves: L (lambda, skewness) power needed to transform the data into normality, M (mu, median) and S (sigma, coefficient of variation). The percentiles curves were produced using the following equation:

$$C_{100\alpha} = M(1 + LSz_\alpha)^{\frac{1}{L}} \tag{1}$$

Z-scores quantify how far an individual's measurements deviate from the median measurements of a population. This calculation is based on the following formula:

$$Z = \frac{\left[\left(\frac{Measurement}{M}\right)^L - 1\right]}{LS} \tag{2}$$

Formula 2 allows us to calculate Z-scores for specific values, such as 60 (ml/kg•min^{-1}) and 70 (ml/kg•min^{-1}), which we selected at age 18, the age of transition from adolescence to adulthood [33]. Using Formula 1, we can then accurately interpret the percentiles corresponding to these values.

2.7. Statistical analyzes

The 50th percentiles of maximal oxygen uptake (VO_2max) of Tunisian boy soccer players are compared with those of Greek boy soccer players [20], as well as with those of untrained boy participants of Colombia [34], US [35], and with data sets of international 20 m shuttle run test [36].

Data are presented as mean (M) and standard deviation (SD). The Kolmogorov-Smirnov test was used to check the normality assumption before using parametric tests.

Comparisons between all age groups were examined using a one-way ANOVA test. The magnitude of change expressed by Cohen's d coefficient was used to provide a rigorous judgment. Magnitude scales were considered trivial, small, medium, and large, respectively, for values of 0–0.20, >0.20 to 0.50, >0.50 to 0.80, and >0.80 [37].

The relations between different variables were established using the Pearson correlation coefficient (r). All statistical investigation were performed using SPSS software version 26.0 (Chicago, IL, USA) and LMS Chart Maker Pro software version 2.3 (The Institute of Child Health, London) was used to estimate Smooth gender and age-specific percentile curves.

3. Results

The descriptive characteristics according to age groups are shown in Table 1. Briefly, the sample consisted of the following eight age groups: 11–11.99 (11.9 %), 12–12.99 (10.0 %), 13–13.99 (12.4 %), 14–14.99 (12.4 %), 15–15.99 years (13.5 %), 16–16.99 years (13.2 %), 17–17.99 (12.5 %) and 18–18.99 (14.2 %).

The smoothed percentiles (3rd, 10th, 25th, 50th, 75th, 90th, and 97th) MAS and VO_2max parameters according age present in Table 3/Fig. 1, and Table 4/Fig. 2, respectively. Results shown that VO_2max is weakly and positively correlated with age ($r = 0.333$; $P < 0.001$), height ($r = 0.279$; $P < 0.001$), weight ($r = 0.266$; $P < 0.001$), practice period ($r = 0.324$; $P < 0.001$), BMI ($r = 0.10$; $P < 0.05$) parameters. It is inversely correlated with HRmax ($r = -0.247$; $P < 0.001$) (Table 2).

According to the median percentile curves of MAS, the values increase from 10.43 km/h (11 years) to 13.02 (km/h) (18 years). The median values of the VO_2max curves percentiles range from 46.58 (ml/kg•min^{-1}) at 11 years to 50.95 (ml/kg•min^{-1}) at the age of 18 years. In terms of raw data, only the measurements of the [12–12.99] age group are significantly higher ($P < 0.001$; ES = 0.63) than those of the preceding age group [11–11.99].

The VO_2max of 60 (ml/kg•min^{-1}) at 18 years had +1.16 z score compared to the median value among Tunisian players, corresponding to the 87.7th percentile. The prevalence of players who have values below and above this percentile was 84.5 % and 15.5 % respectively. In addition, VO_2max of 70 (ml/kg•min^{-1}) corresponded to the 99.18th percentile (z score = +2.4) at the age of 18 years. The prevalence of values of VO_2max was approximately 0.3% above this percentile.

Fig. 3 illustrated that the median reference values of the Tunisian professionals shifted down compared to those of the Greek professionals and the maximal deviation has reached a value equal to 5.14 (ml/kg•min^{-1}). In addition, the values of 50th percentile of Tunisian professional players are higher than those of school children from other countries. The shifts can reach maximal values equal to 12.28 (ml/kg•min^{-1}) with the American reference, 10.54 (ml/kg•min^{-1}) with the Colombian reference and 8.24 (ml/kg•min^{-1}) with the international reference of the 20 m shuttle run test.

4. Discussion

The aim of our study was to establish standardized reference curves of VO_2max and MAS from 742 adolescent soccer players in Tunisia.

Our main results include smoothed percentile values (3rd, 10th, 25th, 50th, 75th, 90th, and 97th) for VO_2max and MAS, showing that these values increase with age. We found that VO_2max was positively correlated with age, height, weight, trainability, and BMI, whereas it was inversely correlated with HRmax. In addition, we identified specific percentiles, such as the 87.7 and 99.18, as cutoff points that can help categorize players who possess the necessary physiological characteristics for success in professional soccer, or those with exceptionally high aerobic capacity. It is worth noting that the median VO_2max values of Tunisian youth soccer players are lower than those of Greek players.

VO_2max and MAS are often used by scientific researchers [38] as well as by coaches, fitness trainer to control the training load of soccer players [39]. Several researchers have used the Luc-Leger test to calculate these aerobic parameters [40–42], a valid assessment method that dates back to 1988. This test has proven its validity for a wide age range from 6 to 18 years [28]. The VO_2max achieved during testing until exhaustion is known as peak oxygen volume (vO_2peak). It is the best measure of aerobic capacity in children, adolescents, and young adults [43]. It measures the circulatory functional capacity of oxygen supply chain components - anatomical and physiological parameters that start with air intake and finish with cellular oxidative phosphorylation [43].

Table 1
Means ± Standard deviations for Anthropometric Measures, Maximal heart rate (HRmax), Body mass Index (BMI), Maximal Aerobic Speed (MAS) and Maximal oxygen uptake (VO_2max) by age group.

Age group	N	Practice period (years)	Height (m)	Weight (kg)	BMI (kg/m^2)	HRmax (bpm)	MAS (km/h)	$V0_2$max (ml/kg*min^{-1})
11–11.99	88	2.60 ± 0.49	1.43 ± 0.07	38.73 ± 6.35	18.83 ± 2.65	207.56 ± 6.03	11.64 ± 0.80	52.03 ± 3.99
12–12.99	74	3.65 ± 0.48	1.49 ± 0.07	44.29 ± 6.69	19.93 ± 2.86	205.31 ± 5.84	12.80 ± 1.29	54.97 ± 5.42[a]**
13–13.99	92	4.52 ± 0.50	1.56 ± 0.09	50.09 ± 8.80	20.52 ± 2.97	203.89 ± 5.17	13.13 ± 1.30	55.82 ± 5.79
14–14.99	92	5.55 ± 0.50	1.62 ± 0.11	56.92 ± 8.99	21.60 ± 2.45	202.26 ± 4.36	13.18 ± 1.45	55.56 ± 6.61
15–15.99	100	6.41 ± 0.49	1.68 ± 0.08	58.87 ± 5.63	21.03 ± 2.39	201.11 ± 5.34	13.63 ± 1.31	56.64 ± 6.18
16–16.99	98	7.51 ± 0.50	1.72 ± 0.09	62.52 ± 6.49	21.35 ± 2.73	199.84 ± 5.23	13.97 ± 1.25	58.28 ± 6.35
17–17.99	93	8.63 ± 0.53	1.77 ± 0.07	68.20 ± 7.16	21.88 ± 2.13	198.94 ± 5.02	13.74 ± 1.08	57.91 ± 5.66
18–18.99	105	9.67 ± 0.60	1.78 ± 0.08	71.07 ± 7.59	22.54 ± 2.18	195.76 ± 6.07	14.19 ± 1.37	59.55 ± 7.20

**: $P < 0.001$.
[a] difference between 11-11.99 and 12–12.99.

Table 2
Pearson Correlation Coefficients between Maximal Oxygen Uptake (VO_2max) (ml/kg•min^{-1}) and the independents variables.

	Correlation Coefficient	P-value
Age (years)	0.333	<0.001
Trainability (years)	0.324	<0.001
weight (kg)	0.266	<0.001
Height (cm)	0.279	<0.001
BMI (kg/m^2)	0.10	<0.05
HRmax (bpm)	−0.247	<0.001

Table 3
L (Lambda), M (median), S (coefficient of variation) and Percentiles curves of Maximal aerobic speed (MAS) (km/h) for Tunisian soccer players aged 11–18 years.

Age (years)	L	M	S	P3	P10	P25	P50	P75	P90	P97
11	0.46	10.43	0.09	8.82	9.31	9.83	10.43	11.04	11.60	12.18
11.5	0.20	10.79	0.09	9.08	9.60	10.15	10.79	11.46	12.09	12.74
12	−0.04	11.17	0.09	9.36	9.90	10.48	11.17	11.90	12.60	13.34
12.5	−0.23	11.53	0.10	9.63	10.19	10.80	11.53	12.32	13.09	13.91
13	−0.34	11.81	0.10	9.82	10.40	11.04	11.81	12.65	13.48	14.37
13.5	−0.39	11.98	0.10	9.94	10.53	11.19	11.98	12.86	13.73	14.67
14	−0.37	12.10	0.10	10.00	10.61	11.28	12.10	13.00	13.88	14.84
14.5	−0.31	12.21	0.10	10.08	10.70	11.39	12.21	13.12	14.01	14.97
15	−0.22	12.36	0.10	10.19	10.83	11.52	12.36	13.26	14.15	15.10
15.5	−0.10	12.52	0.10	10.33	10.98	11.69	12.52	13.43	14.31	15.24
16	0.02	12.68	0.10	10.46	11.12	11.84	12.68	13.58	14.44	15.34
16.5	0.16	12.77	0.10	10.55	11.22	11.93	12.77	13.66	14.51	15.38
17	0.32	12.83	0.10	10.59	11.27	12.00	12.83	13.71	14.53	15.38
17.5	0.51	12.90	0.10	10.63	11.33	12.06	12.90	13.77	14.58	15.40
18	0.74	13.02	0.10	10.68	11.41	12.16	13.02	13.88	14.67	15.47

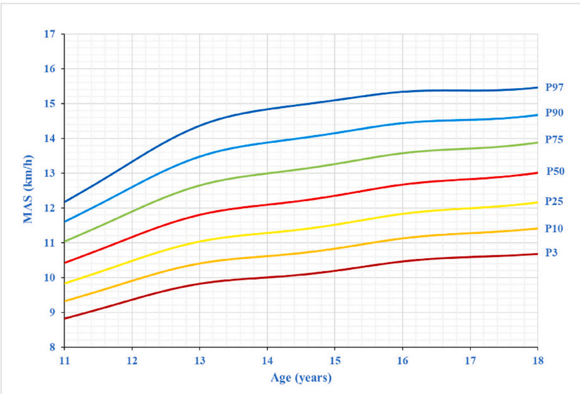

Fig. 1. Smoothed percentiles curves of maximal aerobic speed (MAS) for Tunisian soccer players aged 11–18 years.

Our reference curves of the MAS and VO_2max variables, using the LMS method, were the main results of this study. According to references curves, the MAS 50th percentile values increased with age. Moreover, the MAS at age 18 is the highest compared to other age groups (13.01 vs. 10.43 to 12.83 from ages range from 11 to 17 years) with 24.87% as an evolution rate. While, the median percentiles of theVO_2max curves increased rapidly (8.81 %) until the age of 13, when and the values began to stabilize later.

The increase in VO_2max can be attributed to several factors, including the maximal stroke volume, HRmax, and maximal difference in O_2 between mixed arterial and venous blood, according to Fick's equation [44]. Furthermore, VO_2max is age-adjusted and body size increases from year to year with pubertal status in athletes where peak biological growth sets in. This leads to an increase in the dimensions of the heart and lungs. The increase in heart size is associated with an increase in stroke volume (blood pumped per beat) and cardiac output (product of stroke volume and heart rate, liters per minute) [45]. Similarly, the increase in the size of the lungs (proportional to the growth in size) leads to an increase in lung volume and ventilation [45]. From the age of approximately 6 years to adulthood, the maximal voluntary ventilation approximately doubles (50–100 L per min) [45].Some researches were highlighted the major causes of variance in the growing person. The main of these studies has shown that those differences were linked to anatomical, physiological, and biochemical components that are involved in the creation of aerobic energy [45].

Table 4
L (Lambda), M (median), S (coefficient of variation) and Percentiles curves of Maximal oxygen uptake (VO_2max) (ml/kg•min^{-1}) for Tunisian soccer players aged 11–18 years.

Age (years)	L	M	S	P3	P10	P25	P50	P75	P90	P97	P60 VO_2max	P70 VO_2max
11	0.45	46.58	0.09	38.91	41.27	43.74	46.58	49.52	52.24	55.02	51.71	57.47
11.5	0.28	47.65	0.10	39.23	41.79	44.50	47.65	50.96	54.08	57.29	53.46	60.16
12	0.13	48.83	0.11	39.67	42.41	45.35	48.83	52.54	56.09	59.79	55.38	63.15
12.5	0.01	49.95	0.12	40.06	42.98	46.15	49.95	54.05	58.03	62.24	57.24	66.11
13	−0.06	50.68	0.12	40.17	43.25	46.61	50.68	55.13	59.49	64.15	58.61	68.47
13.5	−0.08	50.89	0.13	39.90	43.09	46.61	50.89	55.59	60.22	65.20	59.29	69.85
14	−0.06	50.78	0.14	39.43	42.73	46.36	50.78	55.65	60.46	65.63	59.49	70.47
14.5	−0.01	50.68	0.14	39.03	42.42	46.15	50.68	55.67	60.57	65.84	59.59	70.75
15	0.07	50.76	0.14	38.82	42.30	46.13	50.76	55.82	60.77	66.07	59.78	70.97
15.5	0.15	50.99	0.14	38.76	42.35	46.27	50.99	56.10	61.08	66.35	60.08	71.20
16	0.24	51.15	0.14	38.68	42.36	46.37	51.15	56.30	61.27	66.49	60.28	71.26
16.5	0.33	51.06	0.14	38.39	42.17	46.24	51.06	56.21	61.13	66.27	60.16	70.92
17	0.44	50.84	0.15	37.97	41.84	45.98	50.84	55.98	60.84	65.87	59.88	70.39
17.5	0.57	50.75	0.15	37.55	41.57	45.82	50.75	55.90	60.71	65.63	59.76	70.00
18	0.73	50.96	0.15	37.22	41.47	45.90	50.96	56.15	60.94	65.76	60.00	70.00

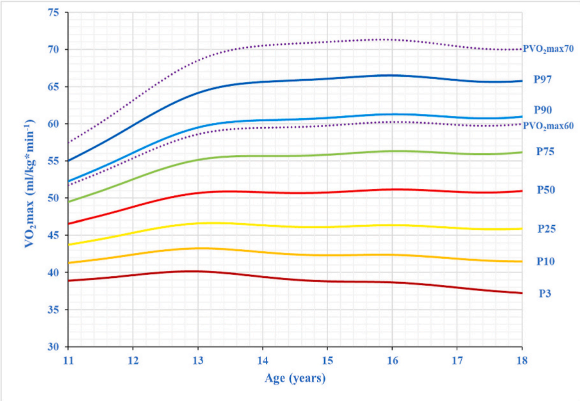

Fig. 2. Smoothed percentiles curves of maximal oxygen uptake (VO_2max) for Tunisian soccer players aged 11–18 years; PVO_2max60: percentile passing through 60 (ml/kg•min^{-1}) at 18 years; PVO_2max70: percentile passing through (ml/kg•min^{-1}) at 18 years.

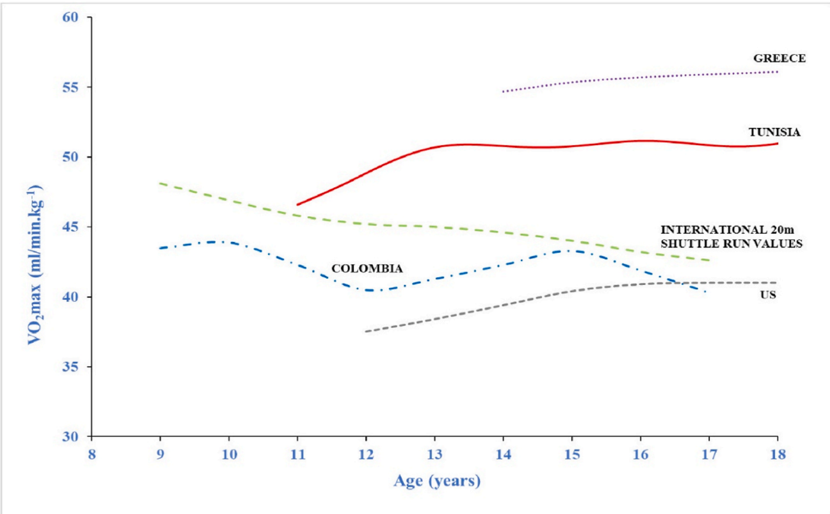

Fig. 3. Comparison of median values (50th percentile) of maximal oxygen consumption (VO_2max) (ml/kg•min^{-1}) of Tunisian soccer players with those of other reference groups: trained adolescents (Greek players) and untrained adolescents (from Colombia, the United States, and the international 20-m shuttle reference dataset).

In this context, previous research suggested that absolute VO_2max increases by 200 (ml.min^{-1}) per year before puberty to around 16 years in males, as a result of an increase in the size of the heart, lungs and muscles [46]. Our results was consistent with the findings of Deprez et al. [47], who argued that the greatest improvement occurred near the peak height velocity (PHV) (when players transitioned from pre-to post-PHV). In addition, study on sixty young Brazilian footballers shows that U-17 athletes perform better than other age groups [48].

Further examining VO_2max values in childhood and adolescence revealed differences between sexes, and trained vs untrained participants. Males' relative VO_2max remains relatively stable throughout childhood at around 50 (ml/kg•min^{-1}), while that of females tends to gradually decline (−20 % between years 8 and 13) [49]. Likewise, smoothed median curves on 2997 untrained American adolescents aged 12 to 18 found a slight increase in estimated VO_2max from 42 (ml/kg•min^{-1}) to 46 (ml/kg•min^{-1}) (+9, 52 %) and a slight decrease in females, from 39 to 37 (ml/kg•min^{-1}) (−5.13 %) [35]. However, the VO_2max performance of 216 professional youth male Greek soccer players aged 14 to 19 (U-15, U-16, U-17, and U-18) showed a higher median percentile value in U19 than in previous age group (56.24 vs. 54.68, 55.35, 55.70, 55.92, and 56.10) with +2.77% evolution rate [20].

The accumulation of specific training loads over the years also appears to have a positive independent influence on the development of aerobic energy pathways in late adolescence [17]. Children who train more than 4 h per week have a 7 % higher hemoglobin mass (Hbmass) than untrained children [50]. The main reason for the increase in Hbmass is an increase in lean body mass, which is modified by trainability [50]. The aerobic capacities of trained individuals are primarily limited by cardiac output or the heart's ability to pump blood. The heart volume of a trained athlete can be twice that of an untrained person [51]. Endurance training also improves skeletal muscle's ability to store glycogen and use fat as an energy source [52,53]. These training effects explain the large differences found between the median percentile values of Tunisian professional soccer players and those of other untrained players references (such as the maximal shift of 12.28 (ml/kg•min^{-1}) found with the American reference) [35].

In addition, our research revealed that the median values of Greek players are higher than those of Tunisian players. This could be due to several factors, including: (1) the level of competition among soccer plays. Significantly higher VO_2max values were reported in selected professional soccer players compared to their unselected counterparts [53]. (2) Inconsistency in VO_2max testing protocols [54]. Our study's VO_2max values are estimated from a field test (20-m shuttle run test), whereas the Greek reference values are measured directly using a gas analyzer during maximal exercise on a treadmill [20]. (3) diet followed by adolescent players. Greek players had followed the same diet (55 % of calories were from carbohydrates, 25 % from fat and 20 % protein) [20]. But there is no information on the diet of our footballers. (4) Sampling [21]. Player's data is collected from nine teams in the national division while that of Greek players was measured in a single team. (5) Nature of the studies: cross-sectional study against a longitudinal study. A longitudinal study better describes the tendency of smooth curves [55].

We also identified the 90th and 97th percentiles as optimal percentiles, passing through VO_2max values of 60 (ml/kg•min^{-1}) and 70 (ml/kg•min^{-1}) at the age of 18 years. Cut-off values of the 90th percentile range from 51.69 (ml/kg•min^{-1}) (11 years) to 60 (ml/kg•min^{-1}) (18 years). Those metrics above which a player can possess to have the physiological attributes required for professional soccer players success. The 97th percentile values range from 57.48 (ml/kg•min^{-1}) at 11 years to 70 (ml/kg•min^{-1}) at 18 years. These VO_2max values can be used to categorize players with extreme aerobic capacities. According to Stølen, Chamari [30], the VO_2max in soccer ranges from 50 to 75 (ml/kg•min^{-1}). This capacity can reach 64,3 (ml/kg•min^{-1}) in junior national team players [56] and 73.9 (ml/kg•min^{-1}) at the age of 18 [57]. Thus, in accordance with Strøyer et al. [58], midfield players can reach 65 (ml/kg•min^{-1}) at the end of puberty. Depending on their age, individual performance level, and position on the field, the best soccer players can achieve VO_2max levels of 65–70 (ml/kg.min^{-1}) [39].

The establishment of the first reference curves of the endurance parameters for adolescent Tunisian soccer players is one of the study's strong points. However, we have also some limitations. We did not structure the players' VO_2max values according to their positions e.g., midfielders have higher values than defenders [53]. This cross-sectional study is another limitation. This type of study, unlike the longitudinal study, would not contribute as a better understanding of the development of aerobic capacity during childhood and adolescence. Individual trajectories were the only way to account for the timing and rhythm of growth and maturation [55].

Future studies should consider expanding their scope to a broader age range that includes children under than 11 years old as well as young adult soccer players above 18 years old. It's also essential to consider different variables, including measuring different body segments and taking into account psychological and socioeconomic factors that may influence the physical condition of young soccer players.

The reference curves obtained in this study represent a first set of normative values. These values can be useful additions to the toolkit of physical trainers and coaches. They may help in categorizing players based on their age and comparing them with their Tunisian soccer counterparts. In addition, these curves allow tracking the evolution of players' aerobic capacity over time, which ultimately facilitates the maintenance of high levels of endurance and intensity during soccer matches.

5. Conclusion

This research establishes normative reference curves for aerobic parameters among Tunisian adolescent soccer players, offering valuable insights for the sports community. By understanding these aerobic benchmarks, coaches and trainers can better assess the aerobic fitness levels of their players in relation to their peers. Such knowledge is crucial for tailoring training programs to enhance players' aerobic capacities, ensuring they meet the demands of high-intensity soccer matches. Additionally, these normative curves serve as a valuable tool for early identification of players who may benefit from targeted interventions to improve their aerobic performance. This study provides a foundational framework for advancing training techniques for Tunisia's youth soccer players, significantly enriching the field of sports science.

Funding

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

CRediT authorship contribution statement

Hatem Ghouili: Writing – review & editing, Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Amel Dridi:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Nejmeddine Ouerghi:** Writing – review & editing, Validation, Resources, Methodology, Conceptualization. **Mohamed Ben Aissa:** Writing – review & editing, Visualization, Validation, Software. **Anissa Bouassida:** Writing – review & editing, Supervision, Conceptualization. **Noomen Guelmami:** Writing – review & editing, Visualization, Validation, Software, Methodology, Formal analysis, Data curation. **Andrew Sortwell:** Writing – review & editing, Methodology, Formal analysis, Conceptualization. **Luís Branquinho:** Writing – review & editing, Resources, Project administration, Data curation. **Pedro Forte:** Writing – review & editing, Visualization, Supervision, Methodology, Investigation. **Ismail Dergaa:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Funding acquisition, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Open access provided by Qatar National Library.

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