

Ultra Trail Performance is Differently Predicted by Endurance Variables in Men and Women

Authors

Ignacio Martinez-Navarro^{1, 2}, Antonio Montoya-Vieco^{1, 2}, Eladio Collado³, Bárbara Hernando⁴, Carlos Hernando^{5, 6}

Affiliations

- 1 Department of Physical Education and Sports, Universitat de Valencia, Valencia
- 2 Sports Health Unit, Vithas Hospital 9 de Octubre, Valencia
- 3 Faculty of Health Sciences, Universitat Jaume I, Castello de la Plana
- 4 Department of Medicine, Universitat Jaume I, Castello de la Plana
- 5 Sports Service, Universitat Jaume I, Castello de la Plana
- 6 Department of Education and Specific Didactics, Universitat Jaume I, Castello de la Plana

Key words

sex, ultraendurance, maximal oxygen uptake, ventilatory thresholds, maximal fat oxidation

accepted 24.08.2020

Published online: 2020

Bibliography

Int J Sports Med

DOI 10.1055/a-1255-3083

ISSN 0172-4622

© 2020. Thieme. All rights reserved.

Georg Thieme Verlag KG, Rüdigerstraße 14,
70469 Stuttgart, Germany

Correspondence

Dr. Ignacio Martinez-Navarro
Physical Education and Sports, University of Valencia,
C/ Gasco Oliag 3
46010 Valencia
Spain
Tel.: 96 3864362, Fax : 96 3864365
ignacio.martinez-navarro@uv.es

ABSTRACT

The study aimed to assess the relationship between peak oxygen uptake, ventilatory thresholds and maximal fat oxidation with ultra trail male and female performance. 47 athletes (29 men and 18 women) completed a cardiopulmonary exercise test between 2 to 4 weeks before a 107-km ultra trail. Body composition was also analyzed using a bioelectrical impedance weight scale. Exploratory correlation analyses showed that peak oxygen uptake (men: $r = -0.63$, $p = 0.004$; women: $r = -0.85$, $p < 0.001$), peak speed (men: $r = -0.74$, $p < 0.001$; women: $r = -0.69$, $p = 0.009$), speed at first (men: $r = -0.49$, $p = 0.035$; women: $r = -0.76$, $p = 0.003$) and second (men: $r = -0.73$, $p < 0.001$; women: $r = -0.76$, $p = 0.003$) ventilatory threshold, and maximal fat oxidation (men: $r = -0.53$, $p = 0.019$; women: $r = -0.59$, $p = 0.033$) were linked to race time in male and female athletes. Percentage of fat mass (men: $r = 0.58$, $p = 0.010$; women: $r = 0.62$, $p = 0.024$) and lean body mass (men: $r = -0.61$, $p = 0.006$; women: $r = -0.61$, $p = 0.026$) were also associated with performance in both sexes. Subsequent multiple regression analyses revealed that peak speed and maximal fat oxidation together were able to predict 66% of male performance; while peak oxygen uptake was the only statistically significant variable explaining 69% of the variation in women's race time. These results, although exploratory in nature, suggest that ultra trail performance is differently predicted by endurance variables in men and women.

Introduction

Ultra trail races (UT) have become extremely popular in recent years and the physiological and health consequences of performing such demanding efforts have increasingly awakened the interest of the scientific community [1, 2]. Additionally, trail running has recently been recognized by the World Athletics as a new running discipline hosting its own Trail World Championships [2]. It is therefore of interest for athletes and coaches to identify those factors that play a

critical role in performance in order to improve training strategies and competition results. Previous studies have explored possible factors related with race time in trail running races ranging from 21 km to 75 km [3–8]. It remains unclear, however, whether the classical physiological variables of endurance running performance (i. e., maximal oxygen uptake, ventilatory thresholds) [9] hold for longer trail running races (i. e., > 100 km). Moreover, the above-mentioned studies were conducted in male samples and there is

lack of investigations comparing performance factors in male and female athletes competing in ultramarathon races [10].

Indeed, controversy remains regarding the importance of running economy (i. e., energy demand for a given velocity of submaximal running) upon trail running performance [11, 12], with some authors reporting a correlation to race time [8, 13] while others do not [4–6]. In addition, the importance of substrate utilization is being increasingly emphasized to predict endurance performance [14, 15]. It is well known that human carbohydrate stores are limited, and exogenous carbohydrate uptake cannot match utilization rates during prolonged endurance exercise, leading in turn to muscle and liver glycogen depletion and thus fatigue and decreased performance [16]. This has sparked interest into strategies to augment fat oxidation during endurance exercise to preserve endogenous carbohydrate stores [15, 17]. Yet, no previous research regarding trail running performance factors have examined whether fat metabolism keeps a significant relationship with race time, as it has been demonstrated for Ironman triathlon [16, 18].

The main aim of the present study was therefore to investigate whether the classical physiological variables of endurance running performance, as well as maximal fat oxidation capacity, were linked to performance in a UT race. Secondly, we wanted to assess whether the abovementioned relationships varied between male and female participants. Lastly, we were interested in exploring possible associations between body composition and race time. Our hypothesis were: (1) peak oxygen uptake, peak speed and speed at first and second ventilatory thresholds would be related with performance; (2) maximal fat oxidation capacity would be independently associated with performance in male but not in female athletes [16, 18].

Materials and Methods

Participants

Forty seven ultra-endurance athletes (29 men and 18 women) were recruited to participate in the study. This research was developed at the Penyalgosa Trails CSP race in 2019. The track consisted of 107.4 km, starting at an altitude of 40 m and finishing at 1280 m above the sea level, with a total positive and negative elevation of 5604 and 4356 m respectively (► Fig. 1). Temperature at the start was 17.2 °C and ranged between 18 and 10.6 °C at mid-race (km 66), and between

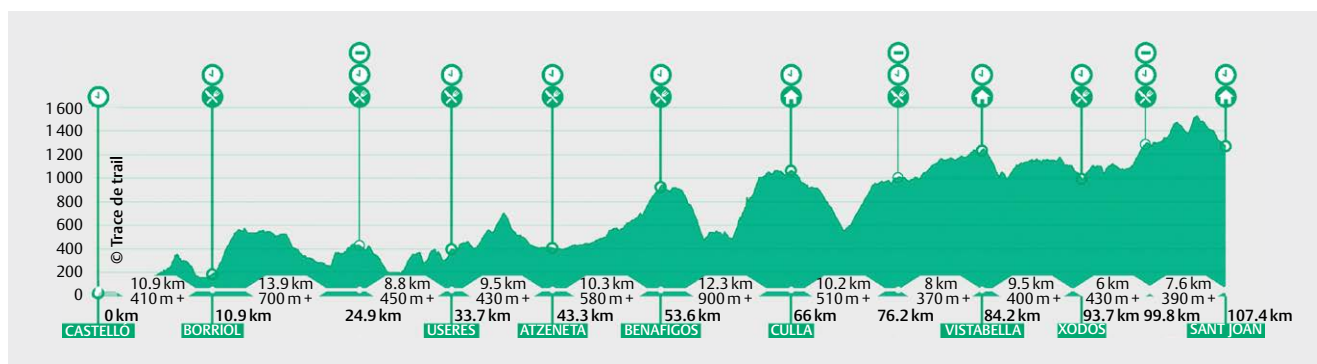
20.1 and 1.5 °C at the finish line. All subjects were fully informed of the procedure and gave their written consent to participate. They were also allowed to withdraw from the study at will. A questionnaire was used to collect demographic information as well as training and competition history. The investigation was conducted according to the Declaration of Helsinki, it obtained the approval from the research Ethics Committee of the University Jaume I of Castellon (Expedient Number CD/007/2019) to be conducted and it met the ethical standards of the International Journal of Sports Medicine [19]. This study is enrolled in the ClinicalTrials.gov database, with the code number NCT03990259 (www.clinicaltrials.gov).

Body composition

Body Mass Index (BMI), percentage of fat mass (%FM) and percentage of lean body mass (%LBM) were evaluated using a bioelectrical impedance weight scale (Tanita BC-780MA, Tanita Corp., Tokyo, Japan). Measurements were performed in a fasted state (> 6 h) with minimal clothing (i. e., running shorts and t-shirt), following the manufacturer's guidelines. The skin and electrodes were cleaned and dried before testing.

Cardiopulmonary exercise test

Cardiopulmonary exercise tests (CPET) were performed on a treadmill (H/P/cosmos pulsar, H/P/cosmos sports & medical GmbH, Nussdorf-Traunstein, Germany) between 2 to 4 weeks prior to the race. Participants were asked to attend the laboratory in a fasted state (> 6 h) and maintain their habitual mixed macronutrient diet the day before the test. Vigorous exercise was not allowed for 48 h before and no training was permitted for 24 h before. All these pre-trial standardisation measures were verbally checked with each participant at his/her arrival to the laboratory. Tests were performed in standard environmental conditions (room temperature between 20 and 22 °C) within the same time frame (between 16 PM and 18 PM). Pulmonary VO_2 and VCO_2 were measured breath-by-breath using an automated online system (Oxycon Pro system, Jaeger, Würzburg, Germany). Gas analysis system was calibrated for ambient temperature and humidity, air flow and VO_2 and VCO_2 concentrations (with a 4.96% CO_2 –12.10% O_2 gas mixture) before each testing session according to manufacturer instructions [20]. After a 4 min warm up at 6 $\text{km}\cdot\text{h}^{-1}$, CPET protocol started at 8 $\text{km}\cdot\text{h}^{-1}$ and speed was increased 1 $\text{km}\cdot\text{h}^{-1}$ every 2 min. When subjects reached a respiratory exchange ratio (RER) > 1.0 increments of 1 $\text{km}\cdot\text{h}^{-1}$ were in-



► Fig. 1 Altitude profile of the race including aid stations (reproduced with permission from race organization).

duced every minute until voluntary exhaustion. VO_2max values were accepted when a plateau (an increase of $< 2 \text{ ml/kg/min}$) or a decline in VO_2 was reached despite increasing workloads and an RER above 1.15 was achieved. If this criteria was not met, a VO_2peak value was taken, defined as the highest VO_2 measured over a 30 seconds period. First and second ventilatory thresholds (VT_1 and VT_2) were determined using Skinner and McLellan [21] guidelines by two independent researchers. Peak speed (V_{peak}), speed and percentage of VO_2peak at VT_1 and VT_2 (V_{VT_1} , V_{VT_2} , $\% \text{VT}_1$ and $\% \text{VT}_2$) were retained for statistical analysis. Subsequently, VO_2 , VCO_2 and ventilation data were averaged over the last 60 s of each 2-min stage and stoichiometric equations described by Frayn [22] were used to calculate fat oxidation rates with the assumption that urinary nitrogen excretion was negligible. Fat oxidation rates were then plotted against the relative exercise intensity ($\% \text{VO}_2\text{peak}$) and a third-degree polynomial regression was used to determine maximal fat oxidation (MFO) and the exercise intensity eliciting MFO (FAT_{max}) for each participant [23]. MFO was normalized to lean body mass (mg/min/kg LBM). Finishing times were obtained from the official timer of the race (LiveTrail®, LiveTrail SARL, France).

Statistical analysis

Statistical analyses were carried out using the Statistical Package for the Social Sciences software (IBM SPSS Statistics for Windows, version 22.0, IBM Corp., Armonk, NY). Normality was checked using the Shapiro-Wilk test and all variables met normality assumptions. Possible sex differences in FAT_{max} and MFO were assessed using an independent samples Student's t-test. Pearson product-moment correlations were computed to assess whether the primary outcome, race time, was associated with body composition variables (BMI, $\% \text{FM}$ and $\% \text{LBM}$) and CPET-derived variables (VO_2peak , V_{peak} , V_{VT_1} , V_{VT_2} , $\% \text{VT}_1$, $\% \text{VT}_2$, FAT_{max} and MFO). This analysis was carried out for the whole sample and for the men and women sample sets. The following criteria were adopted to interpret the magnitude of the correlations: $r \leq 0.1$, trivial; $0.1 < r \leq 0.3$, small; $0.3 < r \leq 0.5$, moderate; $0.5 < r \leq 0.7$, large; $0.7 < r \leq 0.9$, very large; and $r > 0.9$, almost perfect [24]. Afterwards, body composition and CPET-derived variables were entered as independent variables into a stepwise multiple regression analysis with race time as the dependent variable. This analysis was conducted on both the whole sample and the men and women sample sets. Additionally, using the percentage of winning time as a splitting variable, we divided the sample into faster and slower runners (i. e., below and above the mean value for our sample) and we also conducted the abovementioned analysis on those sample sets. Assumptions of linearity, normality, independence (Durbin-Watson statistic values were between 1.5 and 2.5), homoscedasticity and absence of collinearity (all VIF values were below 1.3) were checked in all the multiple regression analyses performed. The significance level was set at $p < 0.05$ and data are presented as means and standard deviations ($\pm \text{SD}$).

Results

From the initial sample (47 athletes), 4 participants did not start the race due to injury and 32 athletes (19 men and 13 women) successfully completed the race. The finishers/starters ratio for the subjects of the present study (i. e. 74.4%) was similar to the ratio when all race

► **Table 1** Sample main characteristics (mean \pm SD).

	All sample (n = 32)	Males (n = 19)	Females (n = 13)
Age (years)	41 \pm 6	40 \pm 5	42 \pm 6
Number of years running	8 \pm 3	8 \pm 2	8 \pm 3
Number of races > 100 km	2 \pm 3	2 \pm 3	2 \pm 4
Weekly training days	5 \pm 1	5 \pm 1	5 \pm 1
Weekly running volume (km)	70 \pm 22	76 \pm 25	61 \pm 13
Weekly positive elevation (m)	1772 \pm 691	1868 \pm 765	1631 \pm 565
Weekly training hours	10 \pm 4	10 \pm 4	9 \pm 5
Strength training (%)	81.3%	73.7%	92.3%
BMI (kg/m^2)	22.8 \pm 2	23.6 \pm 1.6	21.7 \pm 2
FM (%)	15.4 \pm 4.9	12.9 \pm 3.5	19.1 \pm 4.5
LBM (%)	80.3 \pm 4.7	82.7 \pm 3.4	76.8 \pm 4.4
V_{VT_1} (km/h)	10.8 \pm 1.2	11.2 \pm 1.1	10.1 \pm 0.9
$\% \text{VT}_1$ ($\% \text{VO}_2\text{peak}$)	71.9 \pm 5.4	71.8 \pm 6.1	72.1 \pm 4.4
V_{VT_2} (km/h)	13.3 \pm 1.4	13.8 \pm 1.2	12.5 \pm 1.3
$\% \text{VT}_2$ ($\% \text{VO}_2\text{peak}$)	85.6 \pm 5.3	85.3 \pm 4.7	86.1 \pm 6.2
VO_2peak ($\text{ml O}_2/\text{kg/min}$)	54.1 \pm 5.2	55.8 \pm 4.5	51.5 \pm 5.2
V_{peak} (km/h)	15.9 \pm 1.9	16.9 \pm 1.5	14.4 \pm 1.4
FAT_{max} ($\% \text{VO}_2\text{peak}$)	64.3 \pm 9.4	64.9 \pm 10.7	63.4 \pm 7.3
MFO (mg/min/kg LBM)	12.4 \pm 3.1	12.9 \pm 2.6	11.7 \pm 3.6
Abbreviations: Strength training (%), percentage of participants who performed at least one weekly lower-limb strength training in the previous 3 months; BMI, Body mass index; FM, fat mass; LBM, lean body mass; V_{VT_1} , speed at the first ventilatory threshold; $\% \text{VT}_1$, percentage of VO_2peak at the first ventilatory threshold; V_{VT_2} , speed at the second ventilatory threshold; $\% \text{VT}_2$, percentage of VO_2peak at the second ventilatory threshold; VO_2peak , peak oxygen uptake; V_{peak} , peak speed reached at the CPET; FAT_{max} , exercise intensity eliciting MFO; MFO, maximal fat oxidation.			

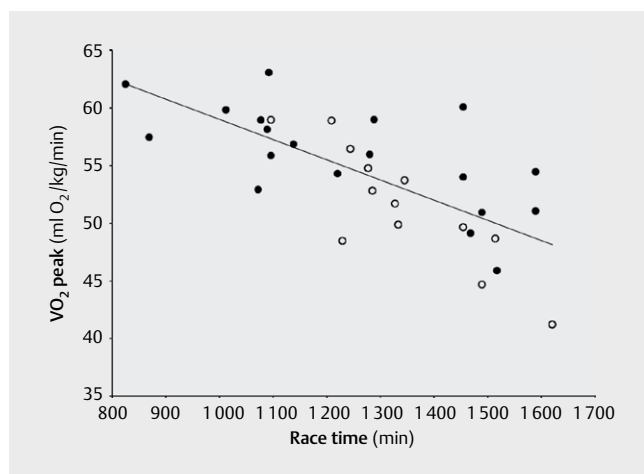
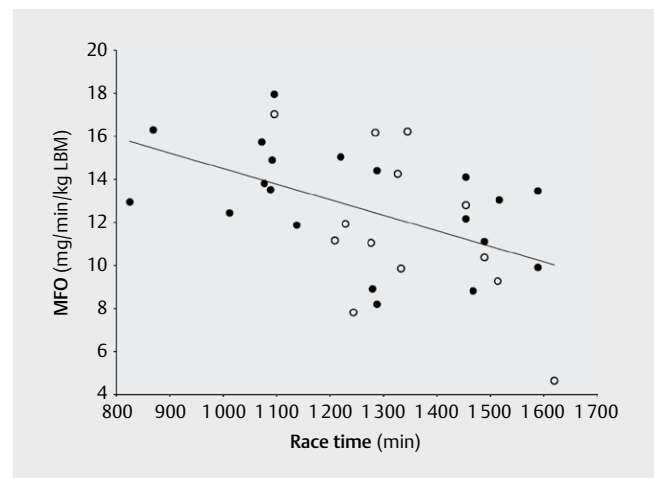
participants were considered (73.8%). Male athletes' average finish time was 20 h 43 min \pm 3 h 58 min, 174% of winning time; while females athletes' average finish time was 22 h 20 min \pm 2 h 24 min, 157% of winning time. All levels of performance were represented in our sample, as shown by their rank ranging from 13th to 395th place (of 397 finishers) in male category, and from 7th to 32th place (of 47 finishers) in female category. Participant characteristics, including demographic information, training and competition history and data from the cardiopulmonary exercise test, are presented in ► **Table 1**.

No significant sex differences were noted in MFO and FAT_{max} . Results from correlational analysis are depicted in ► **Table 2**. Both among men and women, $\% \text{FM}$ and $\% \text{LBM}$ were significantly and largely associated with race time. V_{VT_1} was significantly correlated with performance in men and women, although the magnitude of the correlation was greater for the women sample set (very large vs moderate). V_{VT_2} was significantly and very largely correlated with race time in both sexes. Conversely, neither in women nor in men $\% \text{VT}_1$ was associated with performance; whereas $\% \text{VT}_2$ was linked with race time only in the women sample set. VO_2peak was significantly correlated with performance in men and women, although the magnitude of the correlation was greater for the women sample set (very large vs. large) (► **Fig. 2**). V_{peak} was significantly

► **Table 2** Results from correlational analysis.

	Correlation with race time (r/p)		
	All sample (n = 32)	Men (n = 19)	Women (n = 13)
BMI (kg/m ²)	0.253/0.163	0.482/0.037	0.523/0.066
FM (%)	0.575/0.001	0.577/0.010	0.618/0.024
LBM (%)	-0.586/ < 0.001	-0.608/0.006	-0.612/0.026
V_{VT1} (km/h)	-0.579/0.001	-0.486/0.035	-0.757/0.003
%V_{T1} (% VO _{2peak})	-0.199/0.275	-0.148/0.547	-0.526/0.065
V_{VT2} (km/h)	-0.717/ < 0.001	-0.730/ < 0.001	-0.755/0.003
%V_{T2} (% VO _{2peak})	-0.393/0.026	-0.408/0.083	-0.652/0.016
VO_{2peak} (ml O ₂ /kg/min)	-0.670/ < 0.001	-0.629/0.004	-0.848/ < 0.001
V_{peak} (km/h)	-0.693/ < 0.001	-0.743/ < 0.001	-0.692/0.009
FAT_{max} (%VO _{2peak})	0.195/0.285	0.353/0.138	0.344/0.250
MFO (mg/min/kg LBM)	-0.538/0.001	-0.530/0.019	-0.592/0.033

Abbreviations: BMI, Body mass index; FM, fat mass; LBM, lean body mass; V_{VT1}, speed at the first ventilatory threshold; %V_{T1}, percentage of VO_{2peak} at the first ventilatory threshold; V_{VT2}, speed at the second ventilatory threshold; %V_{T2}, percentage of VO_{2peak} at the second ventilatory threshold; VO_{2peak}, peak oxygen uptake; V_{peak}, peak speed reached at the CPET; FAT_{max}, exercise intensity eliciting MFO; MFO, maximal fat oxidation.

► **Fig. 2** Relationship between race time and peak oxygen uptake (VO_{2peak}). Men results are depicted in full circles and women results in empty circles.► **Fig. 3** Relationship between race time and maximal fat oxidation (MFO). Men results are depicted in full circles and women results in empty circles.

correlated with race time in both sexes, but the magnitude of the correlation was greater for the men sample set (very large vs. large). Lastly, neither in women nor in men FAT_{max} was associated with performance, while MFO was largely correlated with race time in both sexes (► **Fig. 3**).

Results from multiple regression analysis are reported in ► **Table 3**. Considering the whole sample, V_{VT2} and MFO together explained 55% of the variation observed in race time (adj R² = 0.549; F_{2,29} = 19.89; p < 0.001). For the men sample set, V_{peak} and MFO together explained 66% of the variation observed in race time (adj R² = 0.658; F_{2,16} = 18.32; p < 0.001). Meanwhile, for the women sample set, VO_{2peak} was the only statistically significant variable explaining 69% of the variation in race time (adj R² = 0.693; F_{1,11} = 28.14; p < 0.001). Lastly, when splitting the sample by relative race time, for the faster runners sample set, V_{peak} was the only statistically significant variable explaining 75% of the variation in race time (adj R² = 0.748; F_{1,16} = 47.46; p < 0.001); while for the slower runners sample set, VO_{2peak} was the only statistically

significant variable explaining 33% of the variation in race time (adj R² = 0.326; F_{1,12} = 5.77; p = 0.033).

Discussion

The main finding of this study was that UT performance, both in men and women, was correlated with classical physiological variables of endurance running performance (V_{VT1}, V_{VT2}, V_{peak} and VO_{2peak}), as well as with MFO and body composition factors (%FM and %LBM). However, multiple regression analysis indicated that V_{VT2} and MFO explained 55% of the variation observed in all participants' race times. Regarding possible sex differences, men performance was independently predicted by V_{peak} and MFO; while VO_{2peak} was the only statistically significant variable explaining the variation in women's race times. The abovementioned regression models were able to explain 66% of the variation in men performance and 69% of the variation in women performance. Lastly, the magnitude of the cor-

► **Table 3** Model summary resulting from stepwise multiple regression analyses.

Analysis 1: All sample (n = 32)										
	Model	Coefficients B	95 % CI for B		Standardized Coefficient	p-value	Partial R	R2	R2 Change	
			Lower	Upper						
1	(Constant)	-1.894	-5.441	1.653		0.284		0.514		
	V_{VT2}	0.734	0.468	1.001	0.717	< 0.001	0.717			
2	(Constant)	-1.720	-5.091	1.651		0.305		0.578		0.064
	V_{VT2}	0.610	0.330	0.890	0.596	< 0.001	0.637			
	MFO	0.147	0.004	0.291	0.280	0.045	0.538			
Analysis 2: Men sample set (n = 19)										
	Model	Coefficients B	95 % CI for B		Standardized Coefficient	p-value	Partial R	R2	R2 Change	
			Lower	Upper						
1	(Constant)	-5.995	-12.539	0.548		0.070		0.553		
	V_{peak}	0.839	0.453	1.225	0.743	< 0.001	0.743			
2	(Constant)	-7.299	-12.975	-1.626		0.015		0.696		0.143
	V_{peak}	0.744	0.406	1.082	0.660	< 0.001	0.760			
	MFO	0.272	0.062	0.482	0.388	0.014	0.566			
Analysis 3: Women sample set (n = 13)										
	Model	Coefficients B	95 % CI for B		Standardized Coefficient	p-value	Partial R	R2	R2 Change	
			Lower	Upper						
1	(Constant)	0.836	-1.891	3.562		0.514		0.719		
	VO_{2peak}	0.127	0.074	0.180	0.848	< 0.001	0.848			
Analysis 4: Faster runners sample set (n = 18)										
	Model	Coefficients B	95 % CI for B		Standardized Coefficient	p-value	Partial R	R2	R2 Change	
			Lower	Upper						
1	(Constant)	-2.493	-5.952	0.966		0.146		0.748		
	V_{peak}	0.681	0.471	0.890	0.865	< 0.001	0.865			
Analysis 5: Slower runners sample set (n = 14)										
	Model	Coefficients B	95 % CI for B		Standardized Coefficient	p-value	Partial R	R2	R2 Change	
			Lower	Upper						
1	(Constant)	3.510	0.556	6.464		0.024		0.325		
	VO_{2peak}	0.063	0.006	0.120	0.570	0.033	0.570			

Abbreviations: V_{VT2} , speed at the second ventilatory threshold; MFO, maximal fat oxidation; V_{peak} , peak speed reached at the CPE; VO_{2peak} , peak oxygen uptake.

relation with performance of V_{VT1} and VO_{2peak} was larger among women; whereas the magnitude of the correlation with performance of V_{peak} was larger among men.

The significant association found between VO_{2peak} and performance coincides with most of previous research in the field [3, 5–7], although not all [8]. Besides, our results highlight a large association between race time and V_{VT1} and V_{VT2} . This relationship contrasts with two recent studies undertaken in shorter trail races (i. e., 27 and 31 km), where authors found no correlation between race time and those two variables [3, 8]. However, it is in agreement with Fornasiero et al. [7], who showed that power output at VT_1 and VT_2 (in W/kg) was associated with performance in a 65-km trail race. Despite keeping in mind that correlation does not imply causation, our results suggest that the importance of submaximal parameters associated with exercise thresholds increases as competition length does, even though peak speed and oxygen uptake remain associated with performance in UT races.

On the other hand, in Ironman triathletes it has been shown that the relationship between MFO and performance is slightly stronger among women, as compared to men [16, 18]. However, when VO_{2peak} was integrated in the analysis, the abovementioned association in women disappeared, unlike the association in men. Authors showed that VO_{2peak} was the only independent variable that predicted women performance. Our results matches with those previously published and extend it to the UT field. Moreover, as far as we are concerned, no study had previously compared the association of V_{VT1} with ultraendurance performance between men and women. The stronger relationship we found between race time and V_{VT1} in women, as compared with men, suggest it could be related with the lower absolute speed at which they performed the race. Notwithstanding, further studies in the field are required to clarify this assumption.

MFO values in our sample were largely higher than previously reported in male ultramarathon runners (12.85 ± 2.64 vs. 7.3 ± 2.5 mg/min/kg LBM) [25]; and compared to previous studies in Ironman athletes [16, 18], values for male runners were also higher (12.85 ± 2.64 vs. 9.05 ± 0.27 mg/min/kg LBM), whereas values for female runners were slightly lower (11.74 ± 3.58 vs. 12.9 ± 0.5 mg/min/kg LBM). Interestingly, contrary to prior investigation [15, 16, 18], our results failed to show a higher MFO for female participants compared to male participants. Overall, our UT runners seem to possess a high fat oxidative capacity. Notwithstanding, differences in CPET protocol (cycling vs running; 2-min vs 3-min stages) and time frame of testing (morning vs afternoon) are known to affect MFO [23,26].

On the other hand, as far as we are concerned, no previous studies have assessed the possible relationship between fat metabolism and performance in UT. Investigations conducted on Ironman triathlon have showed that MFO is associated with finishing time [16, 18], whereas Lima-Silva et al. [27] reported no relationship between 10-km running performance and fat oxidation parameters. Our results thus contribute to propose a greater relevance of fat metabolism in long-lasting endurance events (i. e., Ironman triathlon and UT races) compared to shorter competitions (10-km running). Moreover, the fact that MFO appeared an independent performance predictor in the multiple regression analysis when considering the whole sample and the male sample set highlights the important role of fat metabolism in UT events. Considering that

these races are performed at a HR around 90 % of VT_1 [7], thus a moderate intensity where fat metabolism could supply a large percentage of the required energy, faster UT runners may elicit higher rates of fat oxidation and/or have a greater reliance upon fat as a fuel source during UT races [15, 28]. However, a recent study has failed to show an improvement in fat metabolism among recreational ultramarathon runners following either a polarized or a threshold 12-week training program [25]. Therefore, further research is advocated to aid in establishing training recommendations to increase fat use during UT races and thus preserve carbohydrate stores. Additionally, further studies are needed to confirm whether possessing a high MFO during fasted conditions translates to high rates of fat oxidation during prolonged exercise in a fed state.

Previous research has consistently demonstrated the importance of body composition upon trail running performance [3, 5, 7, 29]. Some studies reported an inverse relationship between %FM and race time [3, 7, 29] whereas others found a positive association between %LBM and performance [5]. In our study both %FM and %LBM appeared correlated to race time. Although these relationships with performance were not independent from the other variables assessed in the study and the usage of bioelectrical impedance analysis leads us to be cautious, current results seem to reinforce previous assumptions regarding the important of body composition in trail running performance, both in male and female athletes.

The predictive strength of our performance model (55 % for the whole sample, 66 % for the men sample set and 69 % for the women sample set) matches Fornasiero et al. [7] results in a 65-km trail race, but it is lower than those previously reported in shorter trail running races (between 27 and 31 km) [3, 6, 8]. Consequently, it could be argued that finishing times are less predictable from laboratory variables in UT races as compared with shorter trail running races. Nevertheless, although our study was performed on a larger sample (even when considering men and women sample sets) than most of previous studies in the field, the sample was not yet large enough to draw robust conclusions and further studies are required to confirm our results. In addition, we acknowledge that additional neuromuscular factors (isometric strength, local endurance strength or downhill running ability) could improve the predictive strength of the proposed UT performance model [4, 6, 30]. Even more, as previously suggested, in UT races factors difficult to objectively measure such as mental toughness or avoidance of gastrointestinal symptoms probably play a relevant role in determining the final result [11].

There are some limitations in our study that should be acknowledged. Although participants were asked to attend the laboratory for the cardiopulmonary exercise test with at least 6 h of fasting, we do not record fasting times of each participant and we recognize that differences in the length of fast may have impacted estimates of MFO and FAT_{max} . It is also acknowledged that testing in a fasted state may entail a limitation to the study design as UT races are performed in fed state. Notwithstanding, as it is known that exogenous carbohydrate uptake cannot match utilization rates during prolonged endurance exercise, running with low carbohydrate availability is not an uncommon situation in the final stages of UT races. Lastly, we must recognize that the results are based on a sin-

gle race with its own characteristics (race profile, terrain, etc.) and cannot be generalized to any UT race. This fact jointly with sample size prevent us from establishing a robust UT performance model (especially when considering sex specific models).

Conclusions

Although the nature of the study and the sample size lead us to be cautious in reaching definitive conclusions, maximal fat oxidation appears to be an important determinant of final race time in UT competitions. At the same time, peak speed and submaximal speeds associated with exercise thresholds, maximal aerobic capacity ($VO_2\text{peak}$), and body composition (percentage of fat mass and lean body mass) are also linked to performance in those races. Moreover, in male athletes, maximal fat oxidation is associated with race time independently of the classical physiological variables of endurance running performance; while maximal aerobic capacity and V_{VT1} seem to be stronger performance predictors among female athletes.

Therefore, current results support that UT coaches should undertake training strategies to upregulate fat oxidation during submaximal exercise and include workouts aimed both at improving submaximal (V_{VT1} and V_{VT2}) and maximal (V_{peak} and $VO_2\text{peak}$) capacities. In a similar way, clinicians are encouraged to assess fat metabolism, as well as $VO_2\text{peak}$ and ventilatory thresholds, when performing CPET in ultraendurance athletes. Further research is needed in order to establish the mechanisms responsible for training-induced changes in MFO. Future studies should also look into additional variables that could have an impact on UT performance, and investigate whether the application of the abovementioned training strategies improve athletes' performance in UT races.

Acknowledgements

Current research could be carried out thanks to the collaboration of Vithas Hospitals group, Penyalgosa Trails and Catedra Endavant Villarreal CF de l'Esport. Authors are also grateful to all the staff involved in the organization of the race and all runners and volunteers participating in this study. The funders had no involvement in the study design, data collection, analysis and interpretation, writing of the manuscript and decision to submit the paper for publication.

Conflict of Interest

The authors declare that they have no conflict of interest.

References

- [1] Knechtle B, Nikolaidis PT. Physiology and pathophysiology in ultra-marathon running. *Front Physiol* 2018; 9: 634. doi:10.3389/fphys.2018.00634
- [2] Scheer V, Basset P, Giovanelli N et al. Defining off-road running: A position statement from the ultra sports science foundation. *Int J Sports Med* 2020; 41: 275–284
- [3] Alvero-Cruz JR, Parent Mathias V, Garcia Romero J et al. Prediction of performance in a short trail running race: The role of body composition. *Front Physiol* 2019; 10: 1306. doi:10.3389/fphys.2019.01306
- [4] Balducci P, Clemenccon M, Trama R et al. Performance factors in a mountain ultramarathon. *Int J Sports Med* 2017; 38: 819–826. doi:10.1055/s-0043-112342
- [5] Bjorklund G, Swaren M, Born DP et al. Biomechanical adaptations and performance indicators in short trail running. *Front Physiol* 2019; 10: 506. doi:10.3389/fphys.2019.00506
- [6] Ehrstrom S, Tartaruga MP, Easthope CS et al. Short trail running race: Beyond the classic model for endurance running performance. *Med Sci Sports Exerc* 2018; 50: 580–588. doi:10.1249/MSS.0000000000001467
- [7] Fornasiero A, Savoldelli A, Fruet D et al. Physiological intensity profile, exercise load and performance predictors of a 65-km mountain ultra-marathon. *J Sports Sci* 2018; 36: 1287–1295. doi:10.1080/02640414.2017.1374707
- [8] Scheer V, Janssen TI, Vieluf S et al. Predicting trail running performance with laboratory exercise tests and field based results. *Int J Sports Physiol Perform* 2018; 1–13. doi:10.1123/ijsp.2018-0390
- [9] di Prampero PE, Atchou G, Bruckner JC et al. The energetics of endurance running. *Eur J Appl Physiol Occu Physiol* 1986; 55: 259–266
- [10] O'Loughlin E, Nikolaidis PT, Rosemann T et al. Different predictor variables for women and men in ultra-marathon running-the wellington urban ultramarathon 2018. *Int J Environ Res Public Health* 2019; 16: 1287
- [11] Millet GY, Hoffman MD, Morin JB. Sacrificing economy to improve running performance—a reality in the ultramarathon? *J Appl Physiol* (1985) 2012; 113: 507–509
- [12] Vernillo G, Millet GP, Millet GY. Does the running economy really increase after ultra-marathons? *Front Physiol* 2017; 8: 783. doi:10.3389/fphys.2017.00783
- [13] Lazzar S, Salvadego D, Taboga P et al. Effects of the Etna uphill ultramarathon on energy cost and mechanics of running. *Int J Sports Physiol Perform* 2015; 10: 238–247. doi:10.1123/ijsp.2014-0057
- [14] Beck ON, Kipp S, Byrnes WC et al. Use aerobic energy expenditure instead of oxygen uptake to quantify exercise intensity and predict endurance performance. *J Appl Physiol* (1985) 2018; 125: 672–674. doi:10.1152/jappphysiol.00940.2017
- [15] Maunder E, Plews DJ, Kilding AE. Contextualising maximal fat oxidation during exercise: Determinants and normative values. *Front Physiol* 2018; 9: 599. doi:10.3389/fphys.2018.00599
- [16] Frandsen J, Vest SD, Larsen S et al. Maximal fat oxidation is related to performance in an ironman triathlon. *Int J Sports Med* 2017; 38: 975–982
- [17] Maunder E, Kilding AE, Plews DJ. Substrate metabolism during ironman triathlon: Different horses on the same courses. *Sports Med* 2018; 48: 2219–2226. doi:10.1007/s40279-018-0938-9
- [18] Vest SD, Frandsen J, Larsen S et al. Peak fat oxidation is not Independently related to ironman performance in women. *Int J Sports Med* 2018; 39: 916–923. doi:10.1055/a-0660-0031
- [19] Harriss DJ, MacSween A, Atkinson G. Ethical standards in sport and exercise science research: 2020 update. *Int J Sports Med* 2019; 40: 813–817. doi:10.1055/a-1015-3123
- [20] Rietjens GJ, Kuipers H, Kester AD et al. Validation of a computerized metabolic measurement system (Oxycon-Pro) during low and high intensity exercise. *Int J Sports Med* 2001; 22: 291–294. doi:10.1055/s-2001-14342
- [21] Skinner JS, McLellan TM. The transition from aerobic to anaerobic metabolism. *Res Q Exerc Sport* 1980; 51: 234–248. doi:10.1080/02701367.1980.10609285
- [22] Frayn KN. Calculation of substrate oxidation rates in vivo from gaseous exchange. *J Appl Phys Respir Environ Exerc Physiol* 1983; 55: 628–634

- [23] Amaro-Gahete FJ, Sanchez-Delgado G, Jurado-Fasoli L et al. Assessment of maximal fat oxidation during exercise: A systematic review. *Scand J Med Sci Sports* 2019; 29: 910–921. doi:10.1111/sms.13424
- [24] Thomas J, Nelson J, Silverman S. *Research Methods in Physical Activity*. Champaign: Human Kinetics; 2005
- [25] Perez A, Ramos-Campo DJ, Marin-Pagan C et al. Impact of polarized versus threshold training on fat metabolism and neuromuscular variables in ultrarunners. *Int J Sports Physiol Perform* 2019; 1–8. doi:10.1123/ijsp.2019-0113
- [26] Amaro-Gahete FJ, Jurado-Fasoli L, Trivino AR et al. Diurnal variation of maximal fat-oxidation rate in trained male athletes. *Int J Sports Physiol Perform* 2019; 14: 1140–1146. doi:10.1123/ijsp.2018-0854
- [27] Lima-Silva AE, Bertuzzi RC, Pires FO et al. Relationship between training status and maximal fat oxidation rate. *J Sports Sci Med* 2010; 9: 31–35
- [28] Dandanell S, Meinild-Lundby AK, Andersen AB et al. Determinants of maximal whole-body fat oxidation in elite cross-country skiers: Role of skeletal muscle mitochondria. *Scand J Med Sci Sports* 2018; 28: 2494–2504. doi:10.1111/sms.13298
- [29] Hoffman MD, Lebus DK, Ganong AC et al. Body composition of 161-km ultramarathoners. *Int J Sports Med* 2010; 31: 106–109. doi:10.1055/s-0029-1241863
- [30] Giandolini M, Horvais N, Rossi J et al. Acute and delayed peripheral and central neuromuscular alterations induced by a short and intense downhill trail run. *Scand J Med Sci Sports* 2016; 26: 1321–1333. doi:10.1111/sms.12583