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Abstract

The aims of the study were to describe the physiological profile of a 65-km (4000-m cumulative elevation gain) running mountain ultra-marathon (MUM) and to identify predictors of MUM performance. Twenty-three amateur trail-runners performed anthropometric evaluations and an uphill graded exercise test (GXT) for VO_{2max}, ventilatory thresholds (VTs), power outputs associated with these indices (PMax, PVTs) and heart rate response (HRmax, HR@VTs). Heart rate (HR) was monitored during the race and intensity was expressed as: Zone I (<VT1), Zone II (VT1-VT2), Zone III (>VT2) for exercise load calculation (training impulse, TRIMP). Mean race intensity was 77.1%±4.4% of HRmax distributed as: 85.7%±19.4% Zone I, 13.9%±18.6% Zone II, 0.4%±0.9% Zone III. Exercise load was 766±110 TRIMP units. Race time (11.8±1.6h) was negatively correlated with VO_{2max} (r=-0.66, P<0.001) and PMax (r=-0.73, P<0.001), resulting these variables determinant in predicting MUM performance, whereas exercise thresholds did not improve performance prediction. Anthropometric and physiological variables explained only 59% of race time variance, underlining the multi-factorial character of MUM performance. Our results support the idea that VT1 represents a boundary of tolerable intensity in this kind of events, where exercise load is extremely high. This information can be helpful in identifying optimal pacing strategies to complete such extremely demanding MUMs.

Keywords: *mountain ultra-marathon, heart rate, exercise intensity distribution, training load, thresholds*

Introduction

Mountain ultra-marathons (MUMs) consist of running and walking on mountain trails over a distance longer than the traditional marathon (from 42.2 up to 350 km) with a considerable cumulative elevation gain (up to 25.000m). These events take place in mountain environments and are performed on irregular terrain, presenting positive and negative slopes. Accordingly, to face MUMs, athletes must perform prolonged concentric work against gravity force during ascents and extensive eccentric work during downhill sections (Vernillo et al., 2015). In addition, MUMs participants are exposed to multiple internal and external stressors, from exercise and environment, including possible wide fluctuations in temperature and altitude, and generally have to sustain extreme exercise loads (Millet, G. P. & Millet, 2012).

Because of their peculiarities some authors have suggested MUMs as an outstanding opportunity to investigate the adaptive responses of the human body to the extreme load and stress of ultra-endurance exercises (Millet, G. P. & Millet, 2012). Accordingly, recent studies have assessed the acute consequences, as well as the adaptive responses induced by MUMs. MUMs have been associated with musculoskeletal injuries and skin-related disorders (Vernillo et al., 2016b), negative energy balance (Martinez et al., 2017; Ramos-Campo et al., 2016), severe muscular damage and inflammation (Carmona et al., 2015; Saugy et al., 2013), marked neuromuscular fatigue (Easthope et al., 2010; Millet, G. Y. et al., 2011b; Saugy et al., 2013), cardiac dysfunctions and myocardial damage (Ramos-Campo et al., 2016; Vitiello et al., 2013), alterations in water diffusivity with changes of the inter-cellular space at brain level (Zanchi et al., 2017), impairment in lung functions (Vernillo et al., 2014a; Wuthrich et al., 2015) and in postural control (Degache et al., 2014). Besides the acute consequences, recent studies reported physiological adaptations that seem to occur exclusively following this specific ultra-endurance exercise. In particular specific metabolic adaptation responses, like the reduction of running and walking uphill energy cost, have been reported especially after extreme distance MUMs (Vernillo et al., 2016c; Vernillo et al., 2014b).

Despite the large number of investigations addressing the consequences of these extreme exercise loads, limited information is available about the sustained exercise intensity and the physiological demands faced during MUMs. The knowledge of the intensity profile and the physiological requirements of MUMs can provide essential information for optimal training, nutrition and participation, also considering the growing interest for these events, with annual numbers of races and participants that are increasing considerably (Hoffman, Ong, & Wang, 2010).

Only few studies reported the intensity sustained during a MUM event. In a 54-km (≈2900m d+) MUM the mean intensity reported was 64% of maximal heart rate (HRmax) for the ≈14h of its duration (Clemente-Suarez, 2015). Conversely, the mean intensity of 82% of HRmax was reported in athletes completing a 54-km (2700 d+) MUM in ≈7h (Ramos-Campo et al., 2016). Despite measuring two MUMs with similar characteristics, the mean exercise intensity was markedly different between the two studies, thus making the scenario not clear. Moreover, the lack of a description of participants' exercise capacities does not help the understanding of the elevated time-difference observed in MUMs, that can be related to differences in performance level as trained athletes are typically able to sustain higher exercise intensities for prolonged periods of time (Joyner & Coyle, 2008; Lucia, Pardo, Durantez, Hoyos, & Chicharro, 1998), but also the differences in athletes' motivation in competing or simply being able to complete such extremely demanding races.

In this regard, a detailed analysis of MUM participants' characteristics would certainly enhance the comprehension of the determinants of MUM performance, where many factors have been shown to be involved (Millet, G. Y., Hoffman, & Morin, 2012). In addition MUMs competitions can present large withdrawal rates (Wegelin & Hoffman, 2011). Among the reasons for the considerable drop out in MUMs inadequate pacing strategies (i.e. choice of exercise intensity) must be certainly considered.

In the light of these observations, further investigations seem to be required to characterize the exercise intensity sustained during MUMs, as well as how athletes' efforts are distributed among the intensity spectrum for this kind of ultra-endurance exercise. Accordingly, the aim of the study was to measure the sustained intensity during a 65-km MUM, characterizing the effort on the basis of well-defined exercise intensity thresholds and quantifying the physiological load associated with the competition. The second aim was to identify predictors of MUM performance by means of multiple regression analysis between standardized laboratory testing measures (predictors) and race time (dependent variable).

Methods

Participants

Twenty-three recreational healthy trail-runners (age 40.2±7.3 yr), 17 males and 6 females, were recruited for the study through advertisements on the official website of the race. None of the participants involved had clinical evidence of cardiovascular, neuromuscular, or articular diseases. Information about subjects' training history was collected through a questionnaire (Vernillo et al., 2016b). Participants had 7±7 yrs of training experience in running and 3±3 yrs of experience in MUMs. Usually they ran 7±3 h/week covering 55±31 km weekly. They participated in the competition with the aim to complete it in the best time possible. Before data collection, all participants were properly informed about the experimental protocol and gave their written informed consent for the measures. The experimental protocol was approved by the Ethics Committee of the University the investigators belong to.

Experimental Protocol

The study was conducted in two phases consisting of preliminary laboratory testing and during-race monitoring. This study examined the HR response during a 65-km MUM in relation with HR-based intensity markers: maximal heart rate (HRmax), heart rate at the first and at the second ventilatory threshold (HR@VT1, HR@VT2). All participants visited our laboratories within the two weeks before the competition for the preliminary testing session. Athletes performed a measure of anthropometric characteristics and an uphill running graded exercise test (GXT) to identify physiological parameters, including VO_{2max} and ventilatory thresholds (VT1, VT2), as well as the HR response. Athletes were asked to refrain from caffeine, alcohol and heavy exercise on the day before the tests. All tests were conducted under controlled conditions (20 ± 1°C, 40-60% relative humidity).

Anthropometric characteristics

Body mass (BM), was measured to the nearest 0.1 kg with a digital weighing scale (Seca, Hamburg, Germany). Height was measured to the nearest 0.001 m with a wall-mounted stadiometer (Gima, Milan, Italy). Body composition was performed with plicometry method by an experienced investigator. Skin-fold data were obtained using a skin-fold calliper (Gima, Milan, Italy) and recorded to the nearest 0.2 mm. Measurements were taken twice, and a mean of the two measures was used for body fat calculation. To calculate values of fat mass (FM) and free-fat mass (FFM), the percentage of body fat (%BF) was estimate according to estimated equations (Jackson & Pollock, 1978; Jackson, Pollock, & Ward, 1979).

Graded exercise test

An uphill graded exercise test (GXT), by means of power increments (combined increases of speed and inclination), was conducted on a motorized treadmill (Rodby Innovation AB, Vänge, Sweden). Mechanical power expressed (W/kg) was calculated as [Power = g*v*sin(α)], where *g* was the gravitational acceleration (m/s^2), *v* the belt speed (m/s) and *α* the angle of treadmill inclination. Before the test, each athlete performed a 10 min warm-up at a constant power of 0.5 W/kg. The test started at a workload of 0.5 W/kg with increments of 0.5 W/kg (0.3 W/kg for females) every 3 min until the volitional exhaustion. Cardio-respiratory measures were collected continuously with breath-by-breath method using an automated open-circuit gas analysis system (Quark PFT Ergo, Cosmed Srl, Rome, Italy). HR was recorded continuously during the test by a HR monitor incorporated into the gas analysis system. Careful calibrations of flow sensors and gas analyzers were performed before each measurement according to the manufacturer's instructions.

Competition measurements

The competition was a 65-km MUM, the second edition of Vigolana Trail® (Vigolo Vattaro, TN, Italy) and was held in the first week of June. It involved 4000 m of cumulative elevation gain. The starting point and the finish line were at 725 m altitude. Overall, the race was performed at medium altitude, with an altitude range between 725 and 2100 m. The race started at 6.30 am with a temperature of 20 °C. The recorded temperatures (minimum-maximum) were 20-33 °C. Maximal allowed time for the 65 km MUM was 15.5 hours and the winner completed it in 7.1 hours. 154 participants of 188 starters finished the race (82%) with a mean time of 11.3 ± 1.7 h.

During the race, HR was continuously monitored using portable HR monitors (Polar RS800 SD, Polar Electro, Kempele, Finland) averaged at 5 s intervals. Racing VO_2 was estimated for every subject from the HR responses, according to the equations for the linear relationship between oxygen uptake and HR obtained during the GXT. Due to technical problems related to difficulties of such long-distance events not all participants were successfully monitored during the whole race. The main reason was the discomfort caused by the thoracic belt for HR recording. Thus only 12 (8 males) out of 23 participants' HR profiles were available for the analysis. The characteristics of this sub-group were not significantly different from the whole group of the study, all p values were >0.05.

Data Analysis

The maximal power output (PowerMax), achieved at athlete's exhaustion, was determined according to the equation: PowerMax (W/kg) = power output last stage completed (W/kg) + [*t* (s)/step duration (s) * step increment (W/kg)], where *t* is the time of the uncompleted stage (Kuipers, Verstappen, Keizer, Geurten, & Van Kranenburg, 1985). $VO_{2max}$was defined as the highest values of a 20-s average (Robergs, Dwyer, & Astorino, 2010). Other breath-by-breath data were averaged over 10s for further analysis of other physiological parameters that have been shown to be important determinants of performance in endurance exercise (Lucià, Hoyos, Paèrez, & Chicharro, 2000). The first and the second ventilatory thresholds (VT1 and VT2) were determined from visual inspection by two independent operators according to methods described in detail elsewhere (Ahmaidi et al., 1993; Wasserman, Hansen, Sue, Stringer, & Whipp, 1999). Therefore, it was possible to establish the specific heart rate (HR@VT1 and HR@VT2) and power values associated with these intensities. Exercise intensity distribution during the race was calculated using HR profile and expressed into three zones: Zone I (<VT1) low intensity, Zone II (VT1-VT2) moderate intensity, Zone III (>VT2) high intensity. Total exercise load was calculated by means of the time spent in the three zones multiplied by arbitrary weighting factors, according to Lucia's training impulse method (Lucia's TRIMP) (Lucia, Hoyos, Santalla, Earnest, & Chicharro, 2003). Accordingly, 1 min in Zone I was given a score of 1 TRIMP unit, 1 min in Zone II was given a score of 2 TRIMP units, and 1 min in Zone III was given a score of 3 TRIMP units. The total TRIMP score was obtained by combining the results of the three zones.

Statistical Analysis

All test data are presented as means ± standard deviations (SD). All the data were tested for their normal distribution (Shapiro–Wilk test). The relationships between performance and subjects characteristics were analyzed using Pearson's correlation. To assess the relationship between performance and laboratory variables we conducted a forward stepwise hierarchical multiple regression analysis. We used performance time as dependent variable, and subjects' characteristics as independent factors. Independent factors entered in four steps into the regression model in the following order:

1. Anthropometry (Age, BMI and Body Fat)
2. Anthropometry + maximal values (PowerMax and VO_{2max})
3. Anthropometry + maximal values + values@VT2 (Power@VT2 and VO_2@VT2)
4. Anthropometry + maximal values + values@VT2 + values@VT1 (Power@VT1 and VO_2@VT1)

All statistical analysis was completed using a statistical software (SPSS Inc, Chicago, Illinois, USA). The level of statistical significance was set at $p<0.05$.

Results

Descriptive statistics of preliminary laboratory testing were reported in Table 1. Mean race time for participants in the study was 11.8 ± 1.6 h (range 8.2-14.3 h), 11.5 ± 1.7 h (range 8.2-14.3 h) in HR monitored sub-group. Athletes performed the race at a mean intensity of 140.3 ± 8.6 bpm, 77.1 ± 4.4% of HRmax equal to 89.1 ± 6.1% of HR@VT1. Mean estimated VO_2 was 63.2 ± 9.1% of VO_{2max}.

*****************************Table1 about here**********************************

Representative example of HR response was reported in Figure 1.

*****************************Figure1 about here**********************************

HR distribution during the race was reported in Fig2a. During the race the exercise intensity distribution was: 85.7% ± 19.4% Zone I, 13.9% ± 18.6% Zone II, 0.4% ± 0.9% Zone III (Fig2b). Total exercise load was 766 ± 110 TRIMP units. Correlations between laboratory variables and performance time were reported in Table2.

*****************************Figure2 about here**********************************

*****************************Table2 about here**********************************

Race time was negatively correlated with maximal physiological parameters, VO_{2max} (r=-0.66, P<0.001) and PowerMax (r=-0.73, P<0.001), resulting these variables determinant in predicting MUM performance. In contrast, despite the strong relationships observed with race time, Power@VT2 (r= -0.70, P<0.001) and Power@VT1 (r= -0.71, P<0.001), sub-maximal parameters associated withexercise thresholds did not improve performance prediction.

*****************************Figure3 about here**********************************

Results from multiple regression analysis were reported in Table 3.

*****************************Table3 about here**********************************

Discussion

MUM exercise intensity

Despite the high number of recent investigations performed on MUMs, limited information is available about the sustained exercise intensity and the physiological demands of these events. Most of the knowledge available on ultra-marathons is based on flat running performance, where intensities have been reported to be 60%-70% of VO_{2max} in 6-h events (Davies & Thompson, 1979), decreasing to 40%-50% of VO_{2max} in 24-h events (Millet, G. Y. et al., 2011a). Only few studies, based on HR monitoring, reported the intensity sustained during MUMs. The mean intensities of 64% of HRmax and 82% of HRmax were respectively reported for participants completing a 54-km MUM in ≈14h (Clemente-Suarez, 2015) and ≈7h (Ramos-Campo et al., 2016).

In our study the intensity observed, ≈77% of HRmax, equal to an estimated intensity of ≈63% of VO_{2max}, was comparable to other ultra-endurance events of similar duration (≈10-11h) (Barrero, Chaverri, Erola, Iglesias, & Rodriguez, 2014; Laursen et al., 2005). In ultra-endurance triathlons mean intensities observed were 78% (Barrero et al., 2014) and 83% (Laursen et al., 2005) of HRmax during cycling and 77% HRmax during running (Barrero et al., 2014; Laursen et al., 2005).

Differently, for events of longer duration lower HR values have been usually observed together with a decrease of intensity with time (Gimenez, Kerhervè, Messonnier, Fèasson, & Millet, 2013; Neumayr, Pfister, Mitterbauer, Maurer, & Hoertnagl, 2004). Gimenez and colleagues (2013) observed a decrease from 72% to 62% of HRmax between the first to the last 6 h of a 24-h treadmill running, with mean intensity sustained of 68% of HRmax (Gimenez et al., 2013). Accordingly, our results obtained during a MUM event seem to be in line with other studies on ultra-endurance exercise.

To the best of our knowledge this is the first investigation analyzing the exercise intensity distribution during a MUM, characterizing the effort by means of well-defined exercise thresholds (VTs). In previous mentioned investigations (Clemente-Suarez, 2015; Ramos-Campo et al., 2016) MUM exercise intensity was found to be below the onset of blood lactate accumulation (OBLA), however no evaluation tests were conducted in order to characterize athletes' effort continuously during the competition. According to exercise intensity distribution found in this investigation most of the race was spent in Zone I, below HR@VT1 (Fig2b). In line with our findings, previous authors have suggested that the intensity associated with VT1 cannot be maintained throughout an ultra-endurance event (Laursen et al., 2005), showing that in the running phase of ultra-endurance triathlons athletes performed below HR@VT1 (Barrero et al., 2014; Laursen et al., 2005). Accordingly, in ultra-endurance exercise the existence of an ultra-endurance threshold lower than VT1 and 80% of HRmax has been previously proposed (Laursen et al., 2005; O'Toole, Douglas, & Hiller, 1998). In our study the mean exercise intensity maintained was slightly below 90%HR@VT1. It has been suggested that exercise intensities marginally below VT1 allow a better balance of substrates oxidation, promoting higher fat to carbohydrate utilization, sparing carbohydrate reserves, delaying muscle and liver glycogen depletion, and maintaining blood glucose concentration (Barrero et al., 2014; Laursen et al., 2005; Laursen & Rhodes, 2001). This strategy has been recommended to help ultra-endurance athletes in reducing fatigue and improving performance (Laursen & Rhodes, 2001). Moreover, during ultra-endurance events athletes present large energy expenditures and require constant energy refuelling (Jeukendrup, 2011; Kreider, 1991). Particularly, despite nutritional strategies adopted by the athletes, MUMs competitions, are associated with large energy deficits (Martinez et al., 2017; Ramos-Campo et al., 2016). Thus, the adoption of an optimal exercise intensity, together with an adequate nutritional intake (Jeukendrup, 2011; Martinez et al., 2017), probably represent the best solution to delay the onset of fatigue and compete in MUMs. Accordingly, an intensity slightly lower than VT1 could represents a boundary of sustainable intensity for runners in >10h MUMs, since athletes sustaining a large part of the race in Zone I could manage their energy reserves, avoid nutrient-related fatigue and optimize competitive result. This information observed in runners that successfully completed a 65-km MUM can be helpful for athletes and coaches in order to better plan the trainings and the participation in this kind of events. In particular our findings can help athletes' pacing strategy during MUMs competitions, providing a reference threshold for athletes who aim to complete such extreme races.

MUM exercise load

The three zones approach defining exercise intensity by means of the HR at the two ventilatory thresholds has been extensively used to calculate the exercise load of trainings and competitions (TRIMP), as well as the optimal training intensity distribution, both in endurance and ultra-endurance athletes (Muñoz, Cejuela, Seiler, Larumbe, & Esteve-Lanao, 2014; Seiler & Kjerland, 2006; Stöggl & Sperlich, 2015). HR-based TRIMP score in literature showed training loads of ≈1000-1500 TRIMP units/week in professional cycling (Lucia et al., 2003) , ≈1000 units/week in ultra-endurance tri-athletes (Muñoz et al., 2014), ≈800 units/week elite runners (Billat et al., 2003), ≈400 units/week sub-elite runners (Esteve-Lanao, San Juan, Earnest, Foster, & Lucia, 2005) and ≈800 units/week in elite junior Nordic skiers (Seiler & Kjerland, 2006). Moreover, taking into account competition loads, values of ≈2000 TRIMP units/week during professional road cycling competition (Lucia, Hoyos, Carvajal, & Chicharro, 1999), ≈1000 units during Ironman triathlon

(Muñoz et al., 2014) and ≈800 units during a 24-h cycling race were reported (Bescos et al., 2012). In the light of the above, the ~750 TRIMP units observed in this study can be considered extremely high, especially for amateur athletes, as such values are often reached by endurance athletes during an entire week of training.

MUM performance

The 65-km MUM performance was highly correlated with athletes' VO_{2max} and peak power output reached in the graded exercise test (Fig. 3). By including the oxygen consumption and mechanical power exerted at the ventilatory thresholds, despite being highly correlated with MUM performance, the prediction of race time did not improve (see the results of steps 3 and 4 of hierarchical regression analysis reported in Table 3). Considering the submaximal intensities sustained in MUMs, it was plausible that the oxygen consumptions associated with sub-maximal indices (VO_2@VTs) represented parameters able to predict the performance. Particularly, for endurance exercise, submaximal indices (e.g. power output or speed exerted at the ventilatory thresholds) seem to be more reflective of athletes' performance capability (Impellizzeri, Marcora, Rampinini, Mognoni, & Sassi, 2005; Lucia et al., 1998), as well as better descriptive of training status especially in an homogenous group of athletes (e.g. similar VO_{2max}) (Joyner & Coyle, 2008). Nevertheless for ultra-endurance exercises values associated with these intensity markers seem to be not so determinant (Millet, G. Y. et al., 2011a), resulting maximal values the best performance predictors (Barrero et al., 2014). In line with existing ultra-endurance literature our analysis, conducted in a heterogeneous group of athletes, further showed the importance of maximal values over those associated with exercise thresholds in ultra-endurance exercise, as previously reported for ultra-distance running (Millet, G. Y. et al., 2011a; Millet, G. Y. et al., 2012) and ultra-endurance triathlon (Barrero et al., 2014). In particular, VO_{2max} is still associated with performance also in ultra-endurance events up to 24-h in duration (Lazzer et al., 2012; Millet, G. Y. et al., 2011a). The importance of a high VO_{2max} has been also explained by a favorable metabolic condition, connected with an advantageous substrates utilization, during low intensities observed in ultra-endurance exercises (Millet, G. Y. et al., 2011a). In this regard, high values of VO_{2max} could represent also a beneficial aspect for the sub-maximal intensities and long duration of a MUM.

In the present study the power outputs exerted in graded exercise test, calculated at the level of ventilatory thresholds and VO_{2max}, were better correlated with performance (*r* coefficients ranged from -0.73 to -0.71) than the measure of oxygen consumptions at the same intensities (*r* coefficients ranged from -0.66 to -0.56, see Table 2). Differently from the measure of oxygen consumptions, the measurement of external power output takes into account the efficiency of converting metabolic power in mechanical power (Ettema & Loràs, 2009), representing one of the main determinants of endurance performance (Joyner & Coyle, 2008). Thus, the power output that an athlete can produce, determined by an uphill GXT, may represent an important factor, determining the ascent rate and consequently performance time in uphill sections of a MUM.

The variables derived from anthropometry and a GXT were found to explain only the 59% of MUM performance variance. In this regard, in ultra-distance running events other factors, associated with the extreme character of the races, as the resistance to muscle damage and mental abilities, can play an important role in determining the final result (Millet, G. Y. et al., 2012). In addition an extensively investigated variable in ultra-distance running that was not evaluated in this study is energy cost of locomotion (Lazzer et al., 2012; Millet, G. Y. et al., 2011a; Vernillo et al., 2016c; Vernillo et al., 2015; Vernillo et al., 2014b). The role of energy cost in determining ultra-running performance is still a topic of discussion (Millet, G. Y. et al., 2012). Previous authors have shown that mean energy cost of level running together with VO_{2max} and its fractional utilization can explain the 87% of performance in multi-day running (Lazzer et al., 2012). In addition, as acute consequence of MUM participation, changes in energy cost in different running conditions have been reported (Vernillo et al., 2016c; Vernillo et al., 2015; Vernillo et al., 2014b), with variations that have been shown to be related to MUM performance (Vernillo et al., 2015). For instance, Vernillo and colleagues (Vernillo et al., 2015) reported a positive correlations between race time and the energy cost variation in level and uphill running, after a previous edition of this MUM (65-km). In this study we did not measure the energy cost in different running conditions, and its variation after the race, this may explain why anthropometric and physiological characteristics measured with a GXT accounted only for the 59% of MUM performance variance. Accordingly, these results and the factors above mentioned can further underline the multi-factorial character of MUM performance (Millet, G. P. & Millet, 2012).

Limitations

Some issues should be considered when interpreting the present results. The long distance, the alternation of high elevation gain and loss of the MUM may have favoured the use of conservative pacing strategies, decreasing the risk of premature exhaustion. In addition, several factors might have influenced the HR response during the MUM. The effect of altitude (Bartsch & Gibbs, 2007) as well as subjects' hydration status (Lambert, Mbambo, & Gibson, 1998) could have indeed caused increases in HR. Furthermore, reductions in HR have been observed after ultra-endurance exercise (Lucas et al., 2008; Mattsson et al., 2010) due to plasma volume expansion (Robach et al., 2014) and the desensitization of the heart's adrenergic receptors (Hart et al., 2006; Welsh et al., 2005). The downhill sections of the MUM, generating more exercise-induced muscle damage and fatigue-related outcomes (Giandolini et al., 2016), may have played a direct role on the physiological load not considered in the study. If the athletes stayed for most of the time at an intensity < HR@VT1 during downhill sections the physiological stress may have been quite blind by the intrinsic features of the downhill locomotion (Giandolini et al., 2016; Minetti, Moia, Roi, Susta, & Ferretti, 2002; Vernillo et al., 2016a). Nevertheless, prolonged eccentric loads can lead to an increase of the oxygen consumption, mainly related to the exercise-induced muscle damage (Giandolini et al., 2016; Vernillo et al., 2016a), and thus in the physiological strain. In this regard GPS data could be helpful to contextualize the different contribution of uphill and downhill sections and, thus, the physiological load of MUMs (Kerhervè, Millet, & Solomon, 2015).

Conclusions

Mean exercise intensity during the 65-km MUM was ≈77% of HRmax and most of the race time was spent at intensity below HR@VT1. This finding supports the idea that the first ventilatory threshold represents a boundary of tolerable intensity for amateur runners in a MUM longer than 10h, where the exercise load was found to be extremely high (>750 TRIMP units). The results can be helpful for athletes and coaches in order to better plan the training strategies and the participation in this kind of events. In particular our findings can help athletes' pacing strategy during MUMs competitions, providing a reference threshold for athletes who aim to complete such extreme races.

In addition, the study showed that parameters associated with VO_{2max} were determinant in predicting MUM performance, whereas exercise thresholds did not improve performance prediction in this heterogeneous group of athletes, which is in line with previous research in ultra-endurance events. However, the variables derived from anthropometry and a graded exercise test explained only 59% of race time variance, further underlining the multi-factorial character of MUM performance.

Disclosure of interest

The authors report no conflicts of interest.

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Figures captions

Figure 1. Heart rate response (bpm) and change in altitude (m) during the MUM expressed as % of total race time in a representative participant.

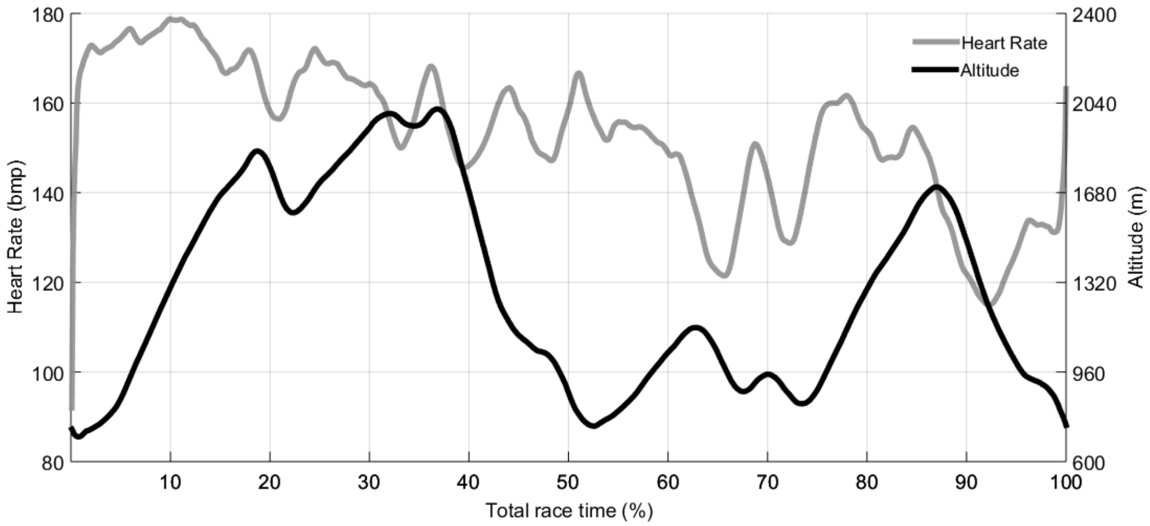

Figure 2. (a) Heart rate distribution during the race. Time spent at different ranges of maximal heart rate expressed as % of total race time. **(b).** Exercise intensity distribution during the race. Time spent in Zone 1 (<VT1), Zone 2(VT1-VT2), Zone 3 (>VT2) expressed as % of total race time.

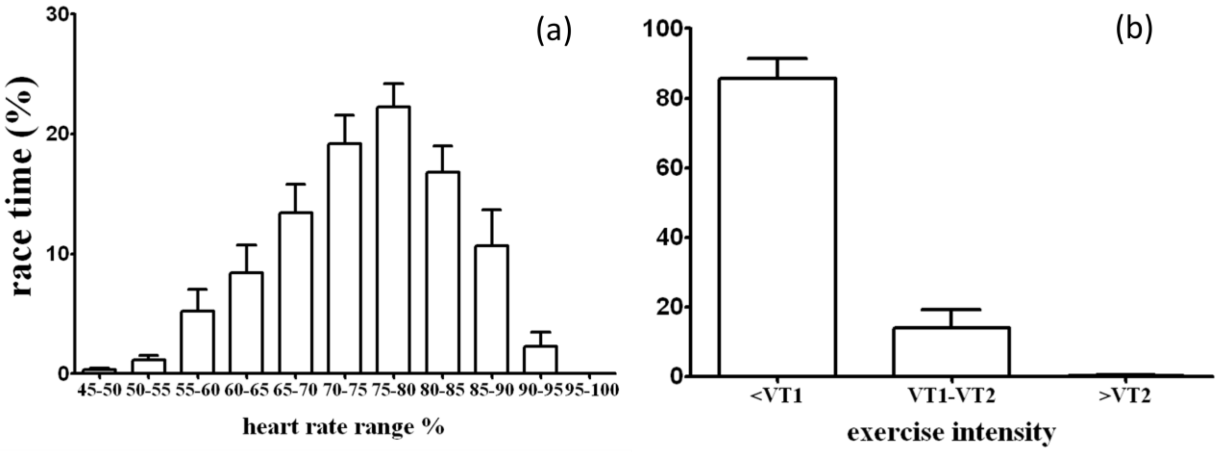

Figure 3. Correlations with performance time in MUM **(a)** Age (years) **(b)** Body Fat (%) **(c)** VO_{2max} (mL/min/kg) **(d)** Maximal power in uphill graded exercise test

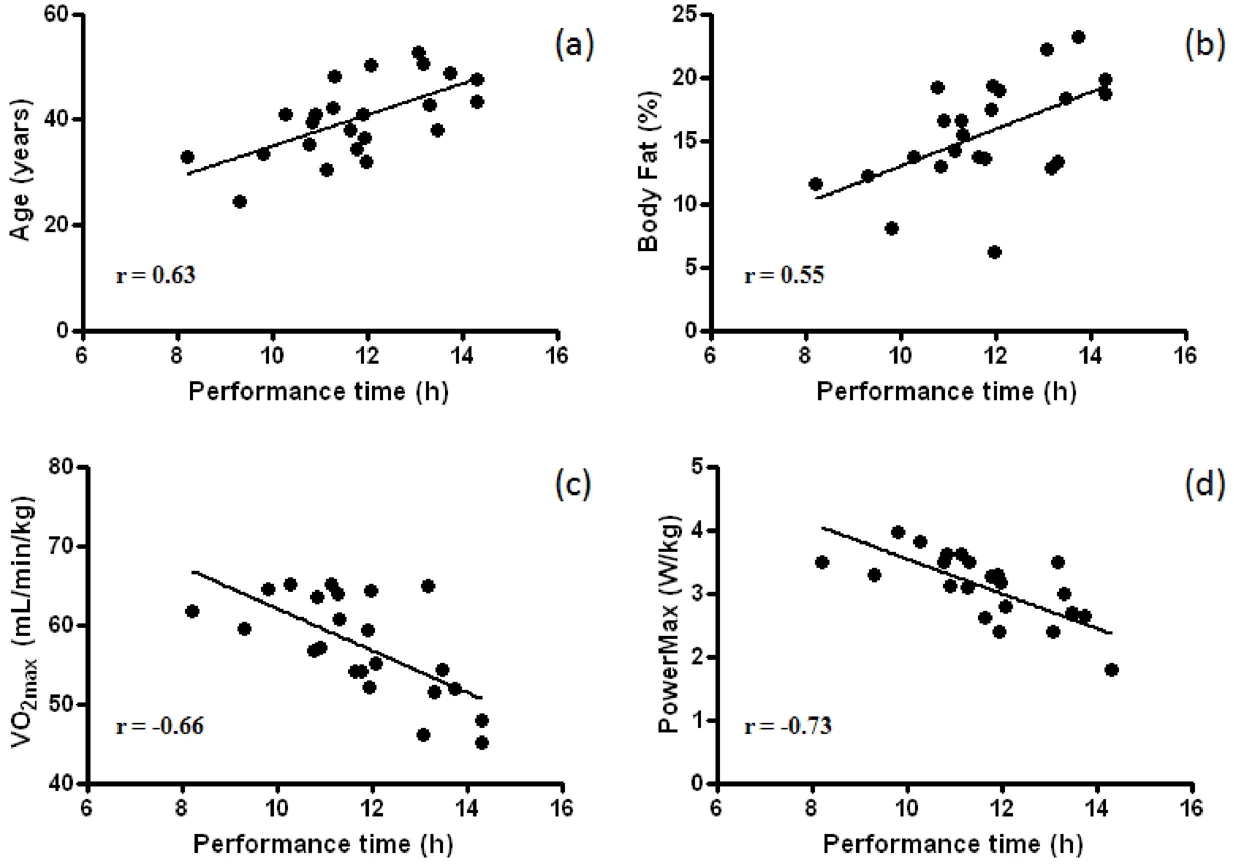

Table 1. Characteristics of the participants resulting from preliminary laboratory testing session.

Characteristics of the subjects

	Whole group (n=23)						**Subgroup HR monitored (n=12)**					
	mean	**±**	**s.d**	**range**			**mean**	**±**	**s.d**	**range**		
Age (years)	40.2	±	7.3	24.4	-	52.7	38.6	±	6.1	30.4	-	48.9
Anthropometry												
Body mass (kg)	69.2	±	11.8	47.0	-	86.1	65.8	±	12.1	47.0	-	83.5
Height (cm)	173	±	8	157	-	187	171	±	9	157	-	181
BMI (kg/m^2)	22.9	±	2.5	18.8	-	27.3	22.2	±	2.7	18.8	-	27.3
Fat-free mass (kg)	58.4	±	9.9	39.6	-	73.0	55.8	±	10.5	39.6	-	68.8
Fat mass (kg)	10.8	±	3.8	3.9	-	19.4	10.0	±	4.1	3.9	-	19.4
Body fat (%)	15.6	±	4.2	6.2	-	23.3	15.1	±	5.0	6.2	-	23.3
Graded exercise test												
VO_{2max} (ml/min/kg)	57.4	±	6.3	45.2	-	65.1	58.4	±	6.2	48.0	-	65.1
VO_2 @VT2 (ml/min/kg)	51.9	±	5.5	40.3	-	59.5	52.9	±	5.0	45.5	-	59.5
VO_2 @VT1 (ml/min/kg)	45.3	±	5.1	33.0	-	52.1	46.3	±	4.5	36.8	-	52.1
HRmax (bpm)	181	±	8	166	-	196	182	±	8	166	-	196
HR @VT2 (bpm)	169	±	10	150	-	186	171	±	10	154	-	186
HR @VT1 (bpm)	155	±	11	128	-	175	158	±	11	136	-	175
PowerMax (W/kg)	3.1	±	0.6	1.8	-	4.0	3.1	±	0.6	1.8	-	4.0
Power@VT2 (W/kg)	2.3	±	0.5	1.4	-	3.0	2.4	±	0.4	1.6	-	3.0
Power@VT1 (W/kg)	1.7	±	0.4	1.0	-	2.2	1.7	±	0.3	1.0	-	2.2
Performance												
Total race time (h)	11.8	±	1.6	8.2	-	14.3	11.5	±	1.7	8.2	-	14.3

VO_{2max} : maximal oxygen consumption; VO_2 @VTs: oxygen consumption at ventilatory thresholds; HRmax: maximal heart rate; HR @ VTs: heart rate at ventilatory thresholds; PowerMax: maximal mechanical power output; Power @VTs: power output at the ventilatory thresholds

Table 2. Relationship between participants' anthropometric and physiological characteristics and MUM performance (race time).

Performance Correlation Analysis (n=23)				
	r	**90% CI**		**p**
Age (years)	0.63	0.44	0.77	**<0.001**
Anthropometry				
BMI (kg/m^2)	0.07	-0.27	0.40	0.384
Fat-free mass (kg)	-0.26	-0.56	0.08	0.112
Fat mass (kg)	0.40	0.12	0.64	0.028
Body fat (%)	0.55	0.29	0.76	**0.004**
Graded exercise test				
VO_{2max} (ml/min/kg)	-0.66	-0.83	-0.44	**<0.001**
VO_2 @VT2 (ml/min/kg)	-0.65	-0.74	-0.35	**<0.001**
VO_2 @VT1 (ml/min/kg)	-0.56	-0.83	-0.44	**0.003**
PowerMax (W/kg)	-0.73	-0.87	-0.56	**<0.001**
Power@VT2 (W/kg)	-0.70	-0.87	-0.46	**<0.001**
Power@VT1 (W/kg)	-0.71	-0.90	-0.45	**<0.001**

VO_{2max} : maximal oxygen consumption; VO_2 @VTs: oxygen consumption at ventilatory thresholds; HRmax: maximal heart rate; HR @ VTs: heart rate at ventilatory thresholds; PowerMax: maximal power output; Power @VTs: power output at ventilatory thresholds

Table 3. Model Summary resulting from forward stepwise hierarchical multiple regression analysis.

Model		Coefficients B	90% CI for B Lower	90% CI for B Upper	Standardized Coefficients	Sig.	Partial R	R	R^2	Adjusted R^2	R^2 Change	Sig. Change
1	(Constant)	7.844	3.323	12.365		0.007		0.682	0.465	0.381	0.465	0.007
	Age	0.103	0.026	0.180	0.481	0.032	0.470					
	BMI	-0.088	-0.279	0.103	-0.142	0.435	-0.180					
	Body Fat	0.116	-0.023	0.255	0.311	0.166	0.313					
2	(Constant)	13.961	7.437	20.486		0.002		0.827	0.684	0.591	0.219	0.011
	Age	0.097	0.033	0.160	0.451	0.016	0.542					
	BMI	0.025	-0.150	0.200	0.040	0.808	0.060					
	Body Fat	-0.057	-0.216	0.103	-0.151	0.545	-0.148					
	VO_{2max}	-0.016	-0.155	0.123	-0.065	0.843	-0.049					
	PowerMax	-1.583	-2.898	-0.268	-0.593	0.052	-0.453					
3	(Constant)	14.479	7.449	21.509		0.003		0.834	0.696	0.554	0.012	0.743
	Age	0.096	0.029	0.163	0.448	0.024	0.543					
	BMI	0.007	-0.185	0.199	0.011	0.950	0.016					
	Body Fat	-0.046	-0.217	0.124	-0.124	0.640	-0.122					
	VO_{2max}	0.135	-0.258	0.529	0.547	0.555	0.154					
	PowerMax	-2.591	-5.449	0.267	-0.971	0.133	-0.380					
	VO2@VT2	-0.170	-0.577	0.236	-0.595	0.474	-0.186					
	Power@VT2	1.279	-2.027	4.585	0.379	0.508	0.172					
4	(Constant)	15.641	7.974	23.309		0.003		0.869	0.756	0.587	0.060	0.242
	Age	0.099	0.032	0.166	0.464	0.021	0.589					
	BMI	0.052	-0.141	0.245	0.084	0.640	0.132					
	Body Fat	-0.124	-0.315	0.068	-0.331	0.273	-0.303					
	VO_{2max}	0.156	-0.243	0.554	0.630	0.501	0.189					
	PowerMax	-3.714	-6.726	-0.701	-1.391	0.048	-0.518					
	VO2@VT2	-0.446	-1.105	0.213	-1.559	0.252	-0.316					
	Power@VT2	5.020	0.072	9.968	1.487	0.096	0.446					
	VO2@VT1	0.268	-0.088	0.625	0.865	0.206	0.347					
	Power@VT1	-3.272	-6.885	0.341	-0.744	0.133	-0.406					

Dependent Variable: Peformance time (h)