PHYSIOLOGICAL DEMANDS OF MOUNTAIN RUNNING RACES

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Abstract:

The aim of this study was to analyze the exercise intensity and competition load (PL) based on heart rate (HR) during different mountain running races. Seven mountain runners participated in this study. They competed in vertical (VR), 10-25 km, 25-45 km and >45 km races. The HR response was measured during the races to calculate the exercise intensity and PL according to the HR at which both the ventilatory (VT) and respiratory compensation threshold (RCT) occurred. The exercise intensity below VT and between VT and RCT increased with mountain running race distance. Likewise, the percentage of racing time spent above RCT decreased when race duration increased. However, the time spent above RCT was similar between races (~50 min). The PL was significantly higher ($p<.05$) during the longest races (145.0±18.4, 288.8±72.5, 467.3±109.9 and 820.8±147.0 AU in VR, 10-25 km, 25-45 km and >45 km, respectively). The ratio of PL to accumulative altitude gain was similar in all races (~0.16 $AU·m^{-1}$). In conclusion, outcomes from this study demonstrate the high exercise intensities and physiologic loads sustained by runners during different mountain races.

Key words: heart rate, exercise intensity, competition load, endurance

Introduction

Participation in mountain running races has experienced a significant increase in recent years (Hoffman, Ong, & Wang, 2010). This fact has motivated the interest of the scientific community for the study of these events (Clemente-Suárez, 2015; Ehrström, et al., 2017; Fornasiero, et al., 2017; Martinez, et al., 2018; Ramos-Campo, et al., 2016; Saugy, et al., 2013; Vernillo, et al., 2015; Wüthrich, et al., 2015). These races consist of running or walking on mountain trails with positive and negative slopes over different distances. Participants can reach an accumulative altitude gain of ~24,000 m during the most extreme events (Saugy, et al., 2013). The *International Skyrunner Federation* (http://www.skyrunning.com/rules/) classifies mountain running races according to their distance (from ~5 to 50-99 km) and elevation gain (from 1,000 to more than 3,200 m vertical climb). Despite a wide variety of disciplines, most research has focused on studying the most challenging events (i.e., mountain ultramarathons) (Clemente-Suárez, et al., 2015; Fornasiero, et al., 2017; Martinez, et al., 2018; Neumayr, et al., 2001; Ramos-Campo, et al., 2016; Saugy, et al., 2013; Vernillo, et al., 2015; Wüthrich, et al., 2015). Collectively, these works have shown a significant impact on athletes participating in mountain ultramarathons: fatigue, muscular damage, negative energy balance, and a high sympathetic modulation. However, a smaller number of studies have been performed on shorter duration races (Ehrström et al., 2017; Giovanelli, et al., 2016). These have focused on examining the metabolic cost of walking or running across a wide range of slopes encountered in vertical kilometer races (i.e., 1,000 m vertical climb and ~5 km) (Giovanelli, et al., 2016) and analyzing the physiological variables that contribute to performance during short mountain races (Ehrström, et al., 2017).

Exercise intensity analysis can provide useful information on which to base conditioning programs (Rodríguez-Marroyo, et al., 2011, 2012). Data derived from the competition demands analysis can be used as reference to adapt training programs and help coaches to develop more specific and scientifically-based training programs. This type of analysis has mostly been performed on endurance events

(Lucía, Hoyos, Carvajal, & Chicharro, 1999; Rodríguez-Marroyo, et al., 2003, 2011; Rodríguez-Marroyo, García-López, Juneau, & Villa, 2009). However, to date there is a paucity of research that analyze the physiological demands of mountain running races (Clemente-Suárez, 2015; Fornasiero, et al., 2017; Ramos-Campo, et al., 2016). To the best of our knowledge, these studies have only focused on analyzing the exercise intensity distribution and estimating energetic demand during mountain ultramarathon races. Thus, using different intensity zones established according to the heart rate (HR) reserve (Clemente-Suárez, 2015; Ramos-Campo, et al., 2016), or HR at the ventilatory thresholds (Fornasiero, et al., 2017) the exercise intensity sustained by mountain runners has been analyzed during 54 and 65 km events. Overall, these works have shown high relative time spend in low intensity zones, i.e., below the ventilatory threshold or <70 % of HR reserve. However, it has been noted that exercise duration affects athletes' effort, which can alter the exercise intensity distribution (Rodríguez-Marroyo, et al., 2012). In this way a decrease in the race time might contribute to sustaining a higher exercise intensity (Rodríguez-Marroyo, et al., 2012). Therefore, the aim of this study was to analyze exercise intensity and competition load experienced by mountain runners during mountain running races of different duration. The secondary aim of the study was to estimate energy expenditure during the races.

Methods

Participants

Seven male mountain runners (mean±*SD*, age 33±6 years, body mass 74.4±7.1 kg, height 177.6±6.2 cm) participated in the study. Four subjects were of high competitive level; they usually finished among the top-20 positions in national events. They were classified as well-trained runners (65-71 $ml \cdot kg^{-1} \cdot min^{-1}$) (De Pauw, et al., 2013). All the subjects were experienced mountain race runners (7±2 years) and had more than 10 years of training experience. They habitually trained 6.2±1.9 times per week (10-20 weekly training hours) and usually competed once every two weeks during the competition period. Written informed consent was obtained from all subjects. The protocol was approved by the Ethics Committee of the University of León, Spain, and conformed to the principles identified in the Declaration of Helsinki.

Procedures

The study was carried out over one season. The subjects performed a graded exercise test during the precompetition period (February) to determine their VO_{2max} and the HR at which both their ventilatory (VT) and respiratory compensation threshold (RCT) occurred. Consequently, the exercise intensity during mountain running races, based on HR was analyzed (Lucía, et al., 1999; Rodríguez-Marroyo, et al., 2003, 2009).

Graded exercise test

Laboratory environmental conditions (22ºC and 30% relative humidity) were standardized for all subjects. All tests were preceded by a 10-minute warm-up period of running at 9-12 $km \cdot h^{-1}$ and free stretching for five minutes. The runners were encouraged to have a light training session the day before and to follow a carbohydrate-rich diet. The test was performed on a treadmill (h/p/cosmos pulsar, h/p/cosmos sports & medical GMBH, Nussdorf-Traunstein, Germany) with a 1% gradient (Jones & Doust, 1996). The initial speed was 6 $km \cdot h^{-1}$ and was increased by 1 $km \cdot h^{-1}$ every minute until volitional exhaustion. The maximal speed was determined as the highest speed maintained for a complete stage plus the interpolated speed from incomplete stages (Kuipers, Verstappen, Keizer, Geurten, & van Kranenburg, 1985). The HR response was measured telemetrically every five seconds (Polar Vantage NV, Polar Electro Oy, Kempele, Finland) and respiratory gas exchange was continuously measured breath-by-breath (Medisoft Ergocard, Medisoft Group, Sorinnes, Belgium). The VO_{2max} and maximal HR were recorded as the highest values obtained for the last 30-second period before exhaustion. The ventilatory (VT) and respiratory compensation (RCT) thresholds were identified according to the following criteria (Davis, 1985): increase in both $VE \cdot VO_2^{-1}$ and $PETO_2$ with no concomitant increase in $VE \cdot VCO_2^{-1}$ for VT, and an increase in both $VE \cdot VO_2^{-1}$ and $VE \cdot VCO_2^{-1}$ and a decrease in $PETCO_2$ for RCT.

Mountain running races

During the competition period (April-August), the HR was recorded using the runners' GPS (Garmin Foreruner 405, Garmin International Inc., Olathe, USA; Suunto Ambit2 S, Suunto Oy, Vantaa, Finland) in different mountain running races in order to analyze exercise intensity and physiological load (PL). Subsequently, using an open-source software (GoldenCheetah, v3.3.0), the data were analyzed according to the cumulative time the runners spent in different effort zones. Three intensity zones were established according to the reference HR values corresponding to VT and RCT (Lucía, et al., 1999; Rodríguez-Marroyo, et al., 2003, 2009, 2011): zone 1, below the VT (low intensity zone); zone 2, between VT and RCT (moderate intensity zone); and zone 3, above RCT (high intensity zone). These zones were used to determine the PL by multiplying the time spent in zone 1, 2 and 3 by the constants 1, 2 and 3, respectively. The total score was obtained by summating the results of the three zones (Foster, et al., 2001). Finally, energy expenditure during the mountain running races was estimated by means of the individual linear relationship between VO_2 and HR obtained during the graded exercise test. It was assumed a caloric equivalent of 4.875 kcal·lO_2^{-1} (Linderman & Laubach, 2004).

The mountain running races were classified into four categories, based on the main disciplines of the *International Skyrunning Federation* (http://www.skyrunning.com/rules/), depending on their distance and elevation gain: vertical race (VR; uphill race, ~5 km and 1,000 m positive vertical climb), 10-25 km race (short uphill/downhill race, ~20 km and ~1,000 m positive vertical climb), 25-45 km race (long uphill/downhill race, ~30 km and ~2,000 m positive vertical climb) and >45 km race (ultra-marathon uphill/downhill race, ~3,000 m positive vertical climb). The runners competed mainly in 10-45 km races and participated in at least one VR and one >45 km race.

Statistical analysis

The results are expressed as mean ± standard deviation (*SD*). The assumption of normality was verified using the Shapiro-Wilk test. Data were analyzed using analysis of variance (ANOVA) with repeated measures. Bonferroni *post-hoc* analysis was used to establish significant differences between means. Values of p<.05 were considered statistically significant. The relation between variables was determined by the Pearson correlation coefficient (*r*). SPSS+ v15.0 statistical software (Chicago, IL) was used.

Results

Physiological characteristics of subjects and major characteristics of mountain running races analyzed in this study are reported in Table 1 and 2, respectively. The total racing time was significantly (p<.05) different (Table 2). The accumulative altitude and both the positive and negative altitude change increased with the length of the races. Maximal HR was similar between races (181±9 bpm). However, the significant differences (p<.05) in mean HR between the VR (171±13 bpm, 91.7±4.0% of maximal HR) and 10-25 km races (166±9 bpm, 89.5±4.3% of maximal HR) versus 25-45 km (155±12 bpm, 84.0±7.7% of maximal HR) and >45 km races (147±6 bpm, 78.6±3.8% of maximal HR) were found.

The percentage of time and time spent in zone 1 increased with the mountain running race distance (Figures 1 and 2). Similarly, the highest (p<.05) percentage of time (Figure 1) and time spent (Figure 2) in zone 2 were found in >45 km races. Although a greater (p<.05) percentage of time in zone 3 was obtained in VR (Figure 1), when the time spent in this exercise intensity zone was analyzed, no significant differences between the different types of races were observed (Figure 2). The absolute PL

Table 1. Physiological characteristics of subjects

	Mean±*SD*
VO_{2max} (ml·kg^{-1}·min^{-1})	59.3±5.5
HR_{max} (bpm)	186±9
VO_2 RCT (ml·kg^{-1}·min^{-1})	49.3±6.1
% VO_{2max} RCT	83.0±4.5
HR RCT (bpm)	167±9
VO_2 VT (ml·kg^{-1}·min^{-1})	36.4±3.4
% VO_{2max} VT	61.5±3.8
HR VT (bpm)	140±7

Note. VO_{2max}=maximum oxygen consumption, HR_{max}=maximal heart rate, RCT=respiratory compensation threshold, VT=ventilatory threshold, %VO_{2max}=percentage of VO_{2max} at which RCT and VT occur.

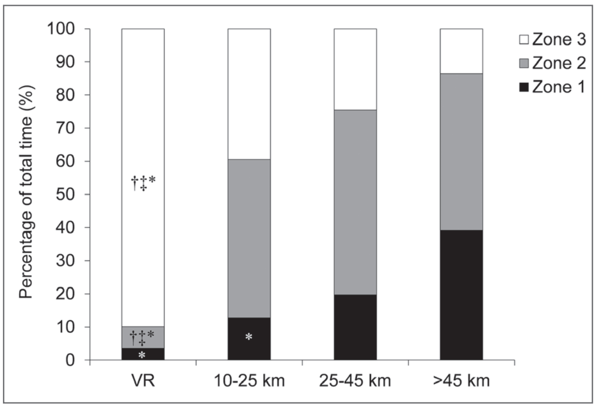

Figure 1. Percentage of total time spent in the three intensity zones analyzed during the mountain races. Zone 1=exercise intensity below ventilatory threshold (VT), Zone 2=exercise intensity between VT and respiratory compensation threshold (RCT), Zone 3=exercise intensity above RCT, VR=vertical race.

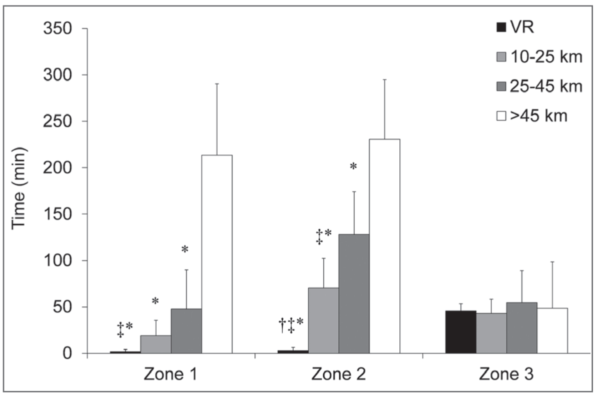

*Figure 2. Mean time spent below ventilatory threshold (Zone 1), between ventilatory and respiratory compensation thresholds (Zone 2) and above respiratory compensation threshold (Zone 3). Values are mean±SD. VR=vertical race, †=significant difference with 10-25 km (p<.05), ‡=significant difference with 25-45 km (p<.05), *=significant difference with >45 km (p<.05).*

Table 2. Descriptive characteristics of mountain running races (mean±SD)

	VR	10-25 km	25-45 km	>45 km
Time (min)	50.9±7.4‡*	132.4±64.5‡*	230.3±52.9*	492.8±157.9
Distance (km)	6.7±1.4†‡*	20.1±4.1‡*	29.7±4.6*	67.4±15.3
Accumulative altitude (m)	1043.4±82.6‡*	2020.9±524.8‡*	3596.5±593.9*	6411.4±2155.9
Positive altitude change (m)	992.6±40.5‡*	1068.8±302.0‡*	1784.0±215.9*	3244.6±1123.4
Negative altitude change (m)	51.0±38.1§†‡*	1052.4±355.3‡*	1812.4±236.1*	3166.8±1035.9
Maximum altitude (m)	2055.3±131.1	1407.6±589.8*	1752.2±288.5	2188.6±347.3
Minimum altitude (m)	1107.0±133.4	762.2±424.0	862.6±191.1	487.6±342.9

Note. VR=vertical race, †=significant difference with 10-25 km (p<.05), ‡=significant difference with 25-45 km (p<.05), *=significant difference with >45 km (p<.05).

Table 3. Absolute and relative physiological load (PL) of mountain running races according their distance (mean±SD)

	VR	10-25 km	25-45 km	>45 km
PL (AU)	145.0±18.4†‡*	288.8±72.5‡*	467.3±109.9*	820.8±147.0
$PL·min^{-1}$ ($AU·min^{-1}$)	2.9±0.1‡*	2.3±0.3*	2.0±0.3	1.7±0.4
$PL·AAG^{-1}$ ($AU·m^{-1}$)	0.16±0.01	0.17±0.03	0.15±0.03	0.15±0.03

Note. VR=vertical race, AU=arbitrary units, AAG=accumulative altitude gain, †=significant difference with 10-25 km (p<.05), ‡=significant difference with 25-45 km (p<.05), *=significant difference with >45 km (p<.05).

was significantly higher (p<.05) during the longest mountain running races (Table 3). However, when PL was normalized by effort time, a greater (p<.05) value was found in shorter races. Finally, the ratio of PL to accumulative altitude gain was similar in all races (Table 3).

The estimated energy expenditure significantly increased (p<.05) in the following order: VR (886.2±145.4 kcal), 10-25 km (2169.9±1004.6 kcal), 25-45 km (3456.4±905.0 kcal) and >45 km (6736.1±1143.6 kcal) races. The energy expenditure per hour was higher in VR (1050.0±159.0 $kcal·h^{-1}$) and 10-25 km (1004.2±89.2 $kcal·h^{-1}$) than in 25-45 km (903.8±162.9 $kcal·h^{-1}$) and >45 km (820.6±46.5 $kcal·h^{-1}$) races.

Racing time correlated with the percentage of time spent in zone 1 (r=.49, p<.001), 2 (r=.35, p<.01) and 3 (r=-.60, p<.001) and with the time spent in zone 1 (r=.80, p<.001) and 2 (r=.84, p<.001). Additionally, negative relationships (p<.001) between race time with the PL normalized by effort time (r=-.64) and energy expenditure per hour (r=-.50) were found.

Discussion and conclusions

There are a few studies that analyze exercise intensity during mountain running races (Clemente-Suárez, 2015; Fornasiero, et al., 2017; Ramos-Campo, et al., 2016). To date, these studies have focused on the most challenging races such as the mountain ultramarathons (Clemente-Suárez, 2015; Fornasiero, et al., 2017; Ramos-Campo, et al., 2016). To the best of our knowledge, the present study is the first one analyzing the physiological demands of mountain running races of different distances. As it has been previously shown the exercise intensity distribution is conditioned by race duration (Rodriguez-Marroyo, et al., 2009, 2012). A higher percentage of time spent in zone 1 and a lower percentage in zone 3 were found in longer races (Figure 1). Possibly, fatigue accumulated over the course of longer races conditioned the athletes' performance in high-intensity zones (Barrero, Chaverri, Erola, Iglesias, & Rodríguez, 2014; Rodriguez-Marroyo, et al., 2009, 2011). In this regard, the effect of competing in a mountain ultramarathon on leg muscles (Clemente-Suárez, 2015; Ramos-Campo, et al., 2016; Saugy, et al., 2013), respiratory muscles (Vernillo, et al., 2014; Wüthrich, et al., 2015) and cardiac (Neumayr, et al., 2001; Ramos-Campo, et al., 2016) fatigue has been documented. Collectively, these factors might have led to a decrease in HR during longer races. It might be thought that the increase in positive altitude change, associated with longer races (Table 2), would lead to an increased HR response (Barrero, et al., 2014). However, downhill running might have accentuated subjects' muscular damage (Giandolini, et al., 2016; Saugy, et al., 2013), limiting their ability to maintain high intensities.

The exercise intensity analyzed (>90% of maximal HR) during VR was similar to those reported during running races lasting from 10 min to one hour such as cross-country (Esteve-Lanao, San Juan, Earnest, Foster, & Lucia, 2005) or in 10 km races (Weston, Mbambo, & Myburgh, 2000) and during simulated orienteering competition (Smekal, et al., 2003). It has been observed that athletes perform above the RCT most of the competition duration during these type of events (Esteve-Lanao, et al., 2005; Weston, et al., 2000). Recently, a mean exercise intensity during a mountain running of 27 km (~89% of maximal HR) very close to that analyzed in this study has been noted (Ehrström, et al., 2017). Similarly, the mean HR values found during races >45 km were in agreement with previous research on ultramarathon races (Fornasiero, et al., 2017; Ramos-Campo, et al., 2016;) or ultra-endurance events (Barrero, et al., 2014; Neumayr, et al., 2002). Mean values of ~82 and ~77% of maximal HR have been reported during mountain races of 54 and 65 km, respectively (Fornasiero, et al., 2017; Ramos-Campo, et al., 2016). These data were higher than that earlier analyzed by Clemente-Suárez (2015) (~64% of maximal HR) during a mountain race of 54 km and 6,441 m of accumulative altitude change. Possibly, it was due to a lower competitive level of the subjects in that study. Neumayr et al. (2002) obtained a negative relationship (r=-.73) between the race time and the percentage of maximal HR during an ultra-endurance cycling event (i.e., 230 km, ~10 h). In the same way, results from our study showed the relationship between race performance and effort exerted at high intensity.

The exercise intensity distribution obtained in the current study (Figure 1) during the >45 km race was very different from that previously described during a 65 km mountain race (Fornasiero, et al., 2017). We found higher percentages of time spent in zones 2 and 3 than those analyzed by Fornasiero et al. (2017) (~47 vs. ~14% and ~14 vs. ~0.5%, respectively). Possibly, a high-performance level of four subjects involved in the current study might determine our results. A greater capacity to perform at high exercise intensities has been previously analyzed in successful athletes (Neumayr, et al., 2002; Rodríguez-Marroyo, et al., 2003). Moreover, it may be speculated that technical demands of a high mountain route (Clemente-Suárez, 2015) or a higher accumulative altitude gain overcome in this study (6400 vs. 4000 m) might increase subjects' metabolic response (Giandolini, et al., 2016). Finally, the specific uphill graded exercise test used by Fornariero et al. (2017) to assess the ventilatory thresholds might lead a rightward shift of these physiological markers and, consequently, a greater exercise intensity observed in zone 1. Indeed, the VT and RCT were identified at ~80 and ~91% of VO_{2max} in the recreational runners who participated in that study (Fornariero, et al., 2017). The ventilatory thresholds have been previously determined at ~70 and ~90% of VO_{2max} in elite professional cyclists (Lucía, et al., 1999) and at ~65 and ~85% of VO_{2max} in sub-elite athletes such as professional cyclists (Rodríguez-Marroyo, et al., 2003, 2009) and middle-distance runners (Esteve-Lanao, et al., 2005).

A remarkable finding of this study was the similar total time spend in zone 3 (~50 min) between the races (Figure 2). This result was consistent with that found by Ramos-Campo et al. (2016) during a mountain ultramarathon (~50 min, ~13% of racing time) when analyzed an intensity zone >90% of HR reserve, which might be considered similar to zone 3. These data might suggest the existence of an optimal pattern of effort at high-intensity to optimize performance in mountain runners. It has been speculated that subjects might subconsciously regulate their effort in order to perform advantageously (Ulmer, 1996). The existence of this phenomenon would be supported by the relative PL analyzed in this study (Table 3). Thus, mountain runners would regulate their effort during races so as not to exceed an upper limit of approximately 0.16 AU per meter of accumulative altitude gain.

Physiological load recorded in this study in VR and 10-25 km, 25-45 km and >45 km races may be compared with those analyzed in professional cyclists during time trial, flat or mountain stages, respectively (Rodríguez-Marroyo, et al., 2009). On the other hand, a PL of ~750 AU has been recently analyzed during a 65-kilometer mountain race (Fornasiero, et al., 2017). These data reflect high exertion during mountain running events, mainly in races >25 km (Table 3). Physiological load obtained in these races represented the weekly training load of well-trained sub-elite endurance runners (~365 AU) (Esteve-Lanao, et al., 2005) or Kenyan elite runners (~800 AU) (Billat, et al., 2003). We found significant differences in $PL \cdot min^{-1}$ between <25 km versus >25 km races, with a higher rate of PL accumulation reflecting a higher intensity during relatively shorter races. The same pattern was observed when the energy expenditure per hour was analyzed. Similar results (700-800 $kcal \cdot h^{-1}$) to those found in >25 km races were previously reported in mountain ultramarathons (Clemente-Suárez, 2015; Ramos-Campo, et al., 2016).

The estimation of exercise intensity on the basis of HR may present different limitations. Physiological (e.g., hydration status, glycogen depletion) and environmental (e.g., altitude, temperature) factors may increase HR responses during exercise (Achten & Jeunkendrup, 2003). Consequently, the effort intensity exerted by our subjects might have been overestimated. A negative energy balance (Clemente-Suárez, 2015; Ramos-Campo, et al., 2016) and an insufficient carbohydrate intake (Clemente-Suárez, 2015; Martinez, et al., 2018) during mountain ultramarathons have been well documented. This might cause hypoglycemia and glycogen depletion during the last part of the longest races (Clemente-Suárez, 2015). However, other factors such as the hydration status or altitude might have had less effect on HR. It has been earlier shown that below ~2000 m the altitude does not appear to have a significant influence on HR (Rodríguez-Marroyo, et al., 2003). Likewise, fluid intake during mountain races seems to be adequate to prevent dehydration (Martinez, et al., 2018). Finally, a methodological drawback of this study was the single graded exercise test performed to analyze exercise intensity over the competition period. In this regard, the stability of HR values corresponding to VT and RCT over time have been observed in endurance athletes (Rodríguez-Marroyo, et al., 2011).

In conclusion, the current study shows that mountain running races are highly demanding and that their intensity and exercise load are related to total race duration. However, a similar time spend above the RCT was observed during all mountain races (~50 min). We believe that runners regulated their effort at high-intensity in order to optimize their performance. Supporting this hypothesis, an upper limit of ~0.16 AU per meter of accumulative altitude gain was obtained during all races. Although the highest competition loads were found in longer races, pace of effort was different between <25 km (~2.5 AU·min^{-1}) versus >25 km (~2.0 AU·min^{-1}) races.

Finally, data from this study may provide useful and practical information on which to base mountain runners' conditioning programs. In addition, the energy expenditure estimated in this research might help to develop nutritional plans for post-race recovery or to promote body composition changes.

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