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ORIGINAL

SLOPE INFLUENCE ON THE TRAIL RUNNER'S PHYSICAL LOAD: A CASE STUDY

INFLUENCIA DEL DESNIVEL EN LA CARGA FÍSICA DEL CORREDOR DE MONTAÑA: UN ESTUDIO DE CASO

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ABSTRACT

This study analysed the internal (heart rate, HR) and external load demands (Speed; Player Load, PL; Power Metabolic, PM; Vertical stiffness, K_{VERT}; approximated entropy, ApEn) during a trail running race in relation to the slope. A national-level athlete (age: 25.3 years; height: 172 cm; weight: 67 kg; VO_{2MAX}: 70.2 ml/kg/min) participated in an official race (Distance: 27.6 km; Accumulated slope: 973 m), analysed in 6 segments related to the slope (without, positive and negative slope). Data was registered through an inertial device WIMU PRO™ (RealTrack Systems, Almería, Spain). The results show an increase of PL/min and PM/min in negative slope and an increase of HR_{AVG} in positive slope. K_{VERT} and ApEn were lower in positive slope, while velocity was faster without slope. It is found a great variability in the trail runner demands related to terrain orography, being important its analysis to design specific training sessions and race planning.

KEYWORDS: Mountain running, inertial devices, heart rate, vertical stiffness, neuromuscular load, fatigue.

RESUMEN

Este estudio analizó las exigencias de carga interna (Frecuencia cardíaca, FC) y externa (Velocidad; Player Load, PL; Power Metabolic, PM; Stiffness Vertical, K_{VERT}; entropía aproximada, ApEn) producidas en función del desnivel del terreno en una carrera de montaña. Un atleta de nivel nacional (edad: 25.3 años; altura: 172 cm; peso: 67 kg; VO_{2MAX}: 70.2 ml/kg/min) participó en una prueba oficial (Distancia: 27.6 km; Desnivel acumulado: 973 m), siendo analizado en 6 segmentos respecto al desnivel (sin desnivel, positivo y negativo). El registro de datos se realizó mediante un dispositivo inercial WIMU PRO™ (RealTrack Systems, Almería, España). Los resultados muestran un aumento de PL/min y PM/min en desnivel negativo y de FC_{AVG} en desnivel positivo. K_{VERT} y ApEn fueron más bajos en desnivel positivo, mientras que la velocidad fue mayor sin desnivel. Se encuentra gran variabilidad en las exigencias en función de la orografía del terreno, siendo importante su análisis para el diseño específico del entrenamiento y la planificación del evento.

PALABRAS CLAVE: Carreras de montaña, dispositivos inerciales, frecuencia cardiaca, stiffness vertical, carga neuromuscular, fatiga.

1. INTRODUCTION

The social phenomenon called *running*, includes different endurance athletic competitions among which the most commonly practiced are long-distance running (half-marathon and marathon), mountain running (high variability of terrain and distance with the influence of slopes) and ultra-endurance races (by time or by distance) performed on: a) trails, b) on a determined track, and c) on city tracks (Consejo Superior de Deportes, 2016). This type of competitions has a very recent history compared with other athletic disciplines and it is developing very quickly (Rojas-Valverde, 2019). Furthermore, these endurance athletic competitions attract increasing numbers of participants as they represent a personal challenge and win participants increased social recognition on the part of their peers (Ruiz-Juan and Zarauz, 2014).

Ultra-endurance competitions are some of the most stressful activities in which a person can participate voluntarily (Eich and Metcalfe, 2009), due to their intensity, duration and the adverse and changing environmental conditions. These conditions require a high level of training due to the great physical (Gutiérrez-Vargas et al., 2020; Millet, 2011) and psychological effort involved (Buceta, de la Llave, Pérez Llantada, Vallejo and del Pino, 2002).

Training monitoring and design is important for achieving the best performance as well as avoiding injury risk (Halson, 2014). The difficulty in training for mountain running is due to the problems for monitoring the competition and planning specific training sessions (Kerhervé, Millet, and Solomon, 2015), given the terrain orography, as the same level of demands could be produced by different factors on an irregular terrain.

Load quantification is divided into internal and external load (Halson, 2014). Among the methods that measure external load are the quantification of the starting power (Jobson, Passfield, Atkinson, Barton, and Scarf, 2009), inertial measurement units with global positioning systems (Taylor, Chapman, Cronin, Newton, and Gill, 2012) and indexes derived from neuromuscular fatigue analysis such as stiffness, ground reaction forces during running (Kvert) and accelerometer load indexes (Cormack, Mooney, Morgan, and McGuigan, 2013; Twist and Highton, 2013).

Recent research has determined neuromuscular fatigue as strength loss after a prolonged exercise, causing alterations in gait biomechanics (Millet, 2011; Millet, Martin, Lattier, and Ballay, 2003; Millet et al., 2011). Different studies have analysed running motor pattern during marathons (Kyröläinen et al., 2000; Martin et al., 2010; Nicol, Komi, and Marconnet, 2007) and ultra-marathons (Millet, 2011; Millet et al., 2011; Morin, Tomazin, Edouard, and Millet, 2011). In the marathon, Nicol, Komi, and Marconnet (2007) found no changes in kinematics, but Kyröläinen et al (2000) reported a significant increase in stride frequency. In the ultra-marathon different studies have evidenced changes in gait biomechanics with higher stride frequency and a reduction of vertical reaction forces and centre of mass oscillations, with the aim of being more efficient (Millet, 2011; Millet et al., 2009; Morin, Samozino, and Millet, 2011).

With respect to the methods that measure internal load, we find rated perceived exertion (RPE) (Borresen and Lambert, 2009), heart rate telemetry (HR) and the lineal relation with maximum oxygen uptake (VO_{2MAX}) (Uth, Sorensen, Overgaard, and Pedersen, 2004), the training impulse (TRIMP) (Banister, 1991), blood lactate which is sensitive to intensity and activity duration (Hughson, Weisiger, and Swanson, 1987), HR variability before and after exercise to analyse if the subjects are adapted to the training/competition stimulus (Pichot et al., 2000), mechanical alterations in muscle (Gutiérrez-Vargas et al., 2020), skin temperature changes (Gutiérrez-Vargas et al., 2017) and biochemical parameters (Gutiérrez-Vargas et al., 2020; Urdampilleta, López-Grueso, Martínez-Sanz and Mielgo-Ayuso, 2014).

To analyse these variables, inertial measurement units have been developed in the last few years to measure internal and external load and synchronise the data obtained at the same time. These devices are composed of different sensors (accelerometers, magnetometers, gyroscopes, GPS, external sensors communication through Bluetooth or Ant+, among others) (Gabbett, 2013) to record and analyse data in real time or after the session. They have also been used previously to analyse cyclic movements (Nedergaard et al., 2017) and team sports (Boyd, Ball, and Aughey, 2013; Cormack et al., 2013), reporting high validity and reliability (Barrett, Midgley, and Lovell, 2014; Gomez-Carmona, Bastida-Castillo, González-Custodio, Olcina, and Pino-Ortega, 2019).

In this respect, considering the difficulties to quantify load demands during mountain running and the need for correct planning to achieve the maximum performance without injury risk, the aims of the present study were: (a) to describe the internal and external load demands during an official mountain running race and (b) to determine if the terrain slope modified the analysed demands.

2. METHODS

2.1. Participants

One national-level mountain runner participated voluntarily in this research (age: 25.3 years; height: 172 cm; weight: 67 kg; muscle mass: 59.1 kg; fat mass: 2.3 kg; VO_{2MAX}: 70.2 ml/kg/min; HR_{REST}: 48 ppm; HR_{MAX}: 198 ppm). The athlete had a maximum aerobic speed (MAS) of 20.2 km/h and three years' experience in mountain running. Prior to starting the protocols, the athlete was previously informed of the details of the investigation and its possible risks and benefits and gave his informed consent in accordance with the code of ethics of the World Medical Association (Declaration of Helsinki, 2013).

2.2. Procedures

The present investigation was conducted during the 2016-2017 season, in an official mountain running race organised by the Mountain Federation of the Region of Murcia (FMRM). The race had an elevation gain of 973 m and a total distance of 27.6 km. The highest point was at 1207 m and the lowest point was at 565 m above sea level. Figure 1 represents the profile of the race divided into segments according to the terrain orography. To create segments, the uphill, downhill or level segments with respect to sea level were used as criteria. The race segments were: segment 1 (level 1); segment 2 (uphill slope 1); segment 3 (level 2); segment 4 (uphill slope 2); segment 5 (downhill slope 1); and segment 6 (downhill slope 2).

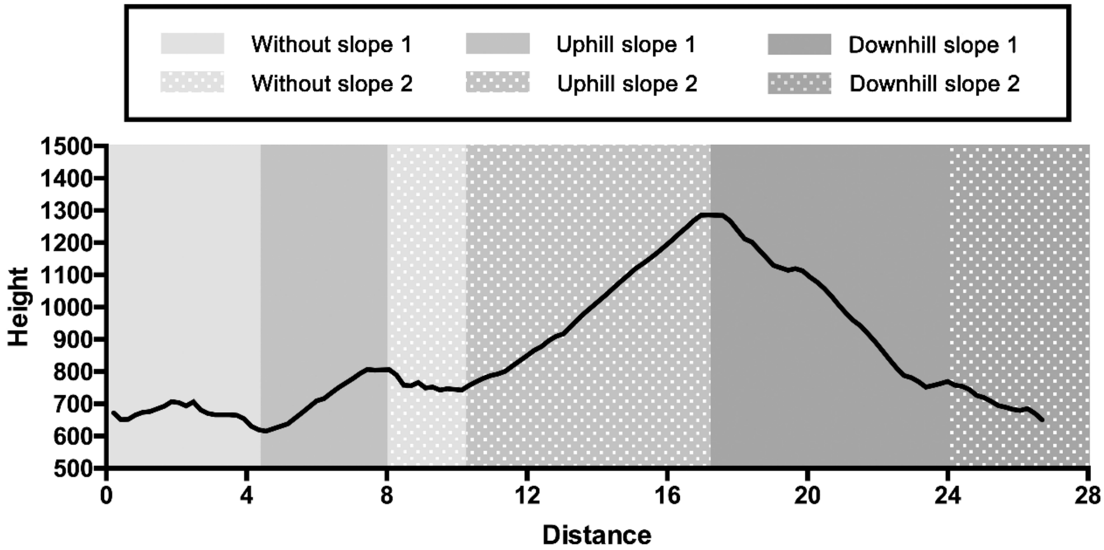

Figure 1. *Race profile and 6 segment divisions related to slope. Y axis (height), X axis (distance).*

The recording protocol was carried out during three sessions that were distributed over two weeks. The anthropometrical measurements were taken, and both the protocol and the objective of the study were explained in the first session. The second session consisted of familiarisation with the equipment during a progressive incremental running treadmill test to evaluate the athlete's maximum performance. Finally, the second week the third session of the study was recorded consisting of the monitoring of an official mountain running competition. Both in the second and third session, the athlete met the research team 15 minutes prior to testing to fit him with the equipment.

The (WIMU PRO™, RealTrack Systems, Almeria, Spain) inertial device was placed in a neoprene vest anatomically adjusted to the athlete between the second and fourth thoracic vertebra. Previously, an autocalibration process was carried out on the device when it was turned on. In this process, three aspects were taken into account: (i) leaving the device immobile during 30 seconds, (b) on a flat surface and (iii) without close contact with magnetic devices (Bastida-Castillo, Gómez-Carmona, and Pino-Ortega, 2016). Data were stored in the internal memory of the device, and later downloaded and analysed using S PRO™ software (RealTrack Systems, Almería, Spain).

2.3. Variables

In the present study, to be able to compare data among segments due to the different total distance and time taken to cover them, the selected variables to analyse load demands were relativised according to execution time, analysing per minute (PL and MP) or the average for each segment (V, ApEn, K_{vert} and HR_{AVG}).

External load

- *Player Load per minute (PL/min):* Accelerometer-derived measurements of total body load in its 3 axes (vertical, anterior-posterior and medial-lateral) have been used to evaluate the neuromuscular load in different athletes (Gomez-Carmona et al., 2019; Reche-Soto, Cardona-Nieto, Diaz-Suarez, Gomez-Carmona, & Pino-Ortega, 2020). It is represented in arbitrary units (a.u.) and is calculated from the following equation at a 100 Hz sampling frequency where: PL_n is the player load calculated in the current instant; n is the current instant in time; $n-1$ is the previous instant in time; X_n, Y_n and Z_n are the values of Body Load for each axis of movement in the current instant in time; X_{n-1}, Y_{n-1} and Z_{n-1} are the values of Body Load for each axis of movement in the previous instant in time.

$$PL_n = \sqrt{\frac{(X_n - X_{n-1})^2 + (Y_n - Y_{n-1})^2 + (Z_n - Z_{n-1})^2}{100}}$$

$$Accumulated\ PL = \sum_{n=0}^{m} PL_n \text{ x } 0{,}01$$

- *Metabolic power per minute (MP/min):* It is the result of the multiplication of velocity (*V*) by the energetic cost of the activity (*CE*) derivate of the inclination and acceleration (Osgnach, Poser, Bernardini, Rinaldo, & Di Prampero, 2010; Reche-Soto et al., 2019). It is represented in W/kg and is calculated using the following formula:

$$PMet = CE \cdot V$$

- *Velocity (V):* Relationship between space or distance (*d*) covered by an object and the time (*t*) to complete it. It is calculated using the following formula:

$$V = d \cdot t^{-1}$$

- *Entropy (ApEn):* Approximate entropy (ApEn) is a measure that depends on the conditional probability that two sequences that are similar for *m* samples remain similar, within a tolerance *r*, in the next sample *m*+1. If a sequence of data contains a large quantity of repetitive patterns (predictable or more regular) it will have a low ApEn, while if the sequence does not have a repetitive pattern (less predictable or irregular) it will have a greater ApEn. (Pincus, 2001). For a temporal series {x(n)} of N finite samples, and defined parameters r and m, ApEn (m, r, N) can be calculated using the following equation (applied on the raw accelerometer signal):

$$ApEn(m,r,N) = ApEn(m,r) = \phi^m(r) - \phi^{m+1}(r)$$

- *Vertical stiffness or ground reaction vertical forces (K_{VERT}):* is the existing relation between the resultant of maximum application force (F_{max}) and the vertical displacement of the centre of mass ($\Delta y_c{}^{-1}$) (Morin, Dalleau, Kyröläinen, Jeannin, and Belli, 2005) and is calculated using the following formula:

$$k_{vert} = F_{max} \cdot \Delta y_c{}^{-1}$$

Internal load

- *Heart rate (HR_{AVG}):* is the number of heart beats per time unit. It is measured in beats per minute and is a physiological response to activity intensity increases. (Bouzas, Ottoline, and Delgado, 2010).

2.4. Instruments

Anthropometrical measures

The height of the subject was measured with a measuring rod (SECA, Hamburg, Germany). The body mass, muscle mass, and fat mass of the athlete were obtained with a body composition monitor composed of eight contact electrodes model BC-601 (TANITA, Tokyo, Japan).

External load

The data were collected by an inertial device called a WIMU PRO^{TM} (RealTrack Systems, Almeria, Spain). The device is composed of different sensors (four accelerometers, three gyroscopes, a magnetometer, a global positioning system (GPS) chip and UWB, among others). GPS with a sampling frequency of 10 Hz, is used for recording velocity and MP/min and its reliability and validity has been evaluated previously (Bastida-Castillo, Gómez-Carmona, De la Cruz Sánchez, and Pino-Ortega, 2018). The 4 accelerometers that compose the device, with a motion detection range of ±16g, ±16g, ±32g and ±400g, and a sampling frequency of 100 Hz are used to record PL/min and K_{VERTt}. The reliability of accelerometers has been evaluated in previous research (Gómez-Carmona, Bastida-Castillo, García-Rubio, Ibáñez, & Pino-Ortega, 2019).

Internal load

Internal load was recorded using a GARMIN^{TM} (Garmin Ltd., Olathe, Kansas, USA) heart rate band that was placed just under the xiphoid process and under the intermammary line, and sent data to the WIMU PRO^{TM} system through Ant+ technology with a sampling frequency of 4 Hz, that was stored in the internal memory of the device. This communication protocol has been evaluated previously (Molina-Carmona, Gomez-Carmona, Bastida-Castillo, and Pino-Ortega, 2018).

Statistical analysis

Data on analysed variables are shown as mean and standard deviation (mean ± SD) to describe all demands during the competition. The analysis of data distribution was made using the Shapiro-Wilk test (Field, 2013), obtaining a normal distribution. Then, a one-way analysis of variance (ANOVA) was performed to compare the demands among segments, using the Bonferroni post-hoc test for pairwise comparison. To calculate the magnitude of differences among segments, Cohen's d was used, and interpreted following Hopkins, Marshall, Batterham and Hanin (2009) as: low effect (0-0.2), small effect (0.2-0.6), moderate effect (0.6-1.2), high effect (1.2-2.0) and very high effect (>2.0). The figures were drawn using Graphpad Prism software (Graphpad Software Inc., La Jolla CA, USA). The statistical analysis was performed using SPSS 24.0 software (SPSS Inc., Chicago IL, EEUU). The statistical significance was established as $p < 0.05$.

RESULTS

Table 1 presents the descriptive analysis of the demands placed on the athlete during a mountain running competition divided by segments related to terrain orography. The highest values in PL/min, MP/min, Velocity and K_{VERT} were found in level segments, while the highest values of HR_{AVG} was performed in uphill segments.

Table 1. Mean and standard deviation of the load demands related to competition segment.

Segment	PL/min (u.a.)		MP/min (W/kg)		HR_{AVG} (bpm)		Velocity (km/h)		ApEn (u.a.)		K_{VERT} (a.u.)	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
SD 1	4.45	1.11	16.29	1.63	182.72	5.64	15.58	1.53	0.52	0.07	29.31	2.84
DP 1	3.37	0.76	13.35	1.36	191.11	1.31	12.85	1.31	0.49	0.05	26.01	1.54
SD 2	4.20	0.68	15.30	1.50	185.21	3.60	14.28	1.64	0.48	0.04	28.91	1.97
DP 2	2.78	0.60	10.34	2.18	189.33	1.70	9.82	1.99	0.46	0.05	25.25	1.49
DN 1	4.00	0.44	13.38	1.22	178.65	3.10	12.47	1.17	0.49	0.06	27.70	2.00
DN 2	3.78	0.64	14.06	1.69	186.52	2.83	13.47	1.72	0.51	0.04	27.31	1.01
Total	3.76	0.71	13.79	1.60	185.59	3.03	13.08	1.56	0.49	0.05	27.41	1.81

Nota. *SD: Level; DP: Uphill slope; DN: Downhill slope; PL/min: Player Load per minute (a.u., arbitrary units); MP/min: Metabolic Power per minute (W/kg, watts/kilo); HR_{AVG}: Average heart rate (bpm, beats per minute); ApEn: Approximate entropy (a.u., arbitrary units); K_{VERTt}: Stiffness (a.u., arbitrary unit); M: Mean; SD: Standard deviation.*

Figure 2 below shows the graphical representation and the comparative analysis of load demands in function of the segments divided by terrain slope. In PL/min, MP/min, Velocity and K_{VERT} the highest values ($p < 0.05$) were found in level segments and the lowest values in uphill segments with a moderate-to-very high effect size (PL/min: $d = 1.82 - 1.15$; MP/min: $d = 3.09 - 1.36$, ; Velocity: $d = 3.24 - 0.96$; K_{VERT}: $d = 1.79 - 1.64$). In contrast, in HR_{AVG} the highest values were found in uphill segments. Finally, no differences were found in ApEn between segments ($p > 0.24$), but the lowest value was recorded in the uphill 2 segment.

In the detailed analysis by segments, PL/min, K_{vert} and Velocity reported the highest values in the level segments ($p < 0.05$), then the downhill segments and finally the uphill segments that recorded the lowest values in these variables. Significative differences were found among different types of slopes ($p < 0.05$), but no differences were found between the segments with the same slope ($p = 0.23 - 0.68$), except in velocity between uphill segment 1 and uphill segment 2 with a high effect size ($p < 0.05$; $d = 1.79$).

There were no significant differences between level segments and with downhill slopes in the MP variable. Only uphill segment 2 revealed significant differences with the rest of the segments ($p < 0.01$). Finally, related to HR_{AVG} the lowest value was found in downhill segment 1 (178.65 ± 3.10 ppm) and the highest values in the two uphill segments (DP1 = 191.11 ± 1.31 ppm; DP2 = 189.33 ± 1.70 ppm), revealing differences with the level segments and the downhill segments ($p < 0.05$). No differences were found between level segments 1 and 2 and downhill segment 2.

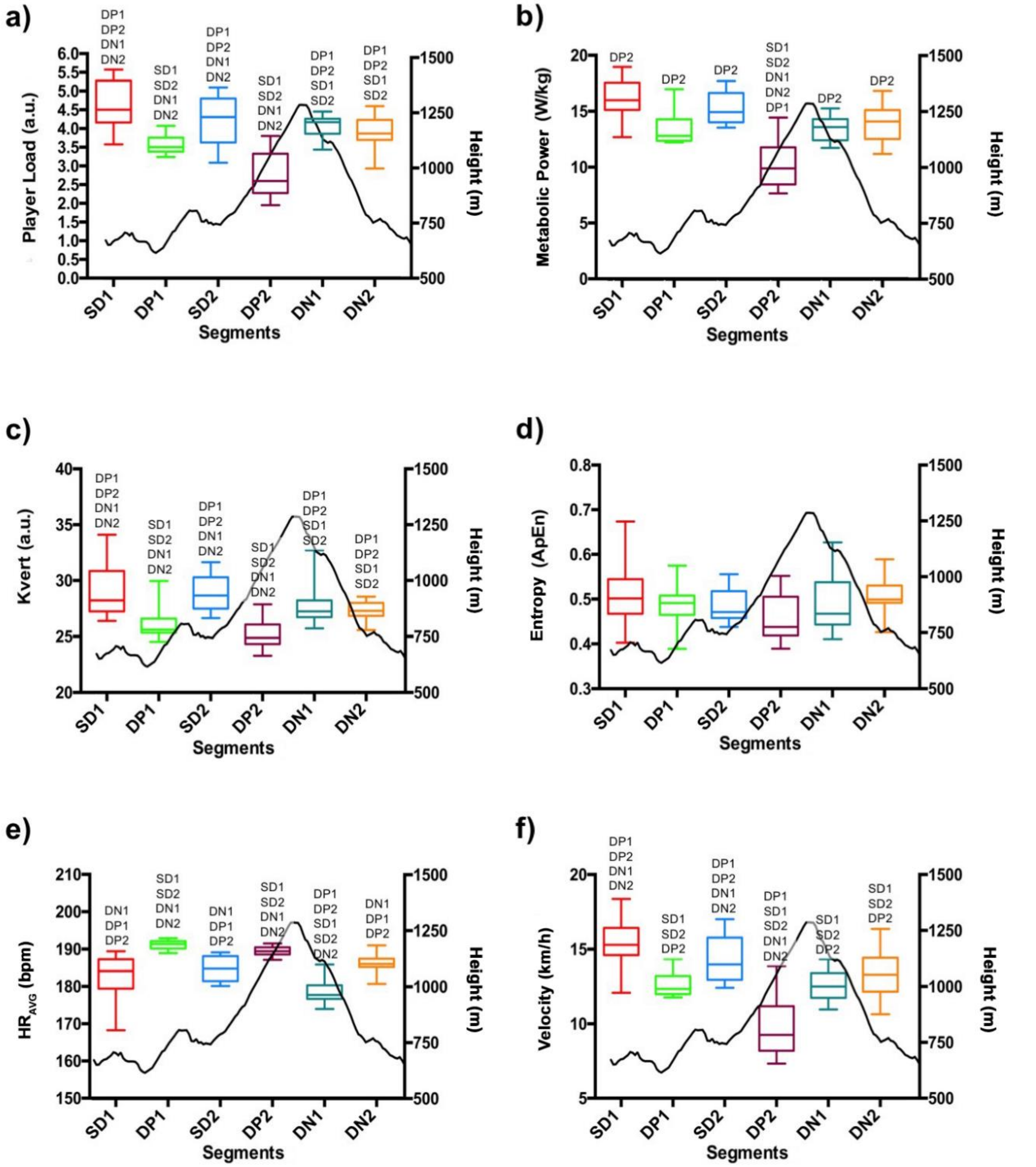

Figure 2. *Box and whiskers plot and significative differences among segments depending of terrain slope in the load demands during an official mountain running race: (a) Player Load (PL), (b) Metabolic Power (MP), (c) Stiffness (K_{VERT}), (d) Approximate entropy (ApEn), (e) Heart rate (HR_{AVG}) and (f) Velocity (V).*

SD1: Statistical differences respect to level segment 1 ($p < 0.05$)
SD2: Statistical differences respect to level segment 2 ($p < 0.05$)
DP1: Statistical differences respect to uphill segment 1 ($p<0.05$)
DP2: Statistical differences respect to uphill segment 2 ($p<0.05$)
DN1: Statistical differences respect to downhill segment 1 ($p<0.05$)
DN2: Statistical differences respect to downhill segment 2 ($p<0.05$)

DISCUSSION

The objectives of the present research were to describe internal and external load during a mountain running competition and to analyse the influence of slope on the race demands. The results obtained determine that the load experienced by the athlete is modified depending on the type of slope during the race (Vernillo et al., 2017). The participants have to adapt their effort over the different segments by varying mechanical and physiological running patterns.

In relation to the PL/min variable, higher values with statistical differences were found in the downhill and level segments with respect to the uphill slopes ($p < 0.05$). The studies that analyse these parameters are related to team sports where the changing situations make the possibility of load quantification difficult (Sparks, Coetzee, and Gabbett, 2017). Increases in the PL/min index are due to significative changes in speed, the product of accelerations and decelerations. Moreover, it has been found that segments covered at higher velocities are related with greater PL/min (Barrett et al., 2014; Buchheit, Gray, and Morin, 2015). Therefore, a higher PL/min value is related with significative speed changes produced by accelerations and decelerations (Sparks, Coetzee and Gabbett, 2017) and higher impacts due to downhill slopes (Vernillo et al., 2017). In contrast, the high PL/min values in level segments is due to an increase in movement intensity recorded as velocity (Barrett, Midgley and Lovell, 2014; Nedergaard et al., 2017). Finally, PL/min could be an appropriate index to analyse mountain running demands due to the high sensitivity as a function of slope and its capacity to identify gait biomechanical changes produced by velocity (Barreira et al., 2017; Barrett et al., 2014; Nedergaard et al., 2017) and fatigue (Barrett et al., 2016; Cormack et al., 2013), among others.

In the case of MP, the results showed that the highest values were found in the faster level segments (Osgnach et al., 2010). The lowest MP values were found in uphill segments where the slowest speed values were recorded. These results are in contrast with previous bibliography, where studies found greater energy costs in uphill segments (Vernillo et al., 2015; 2017), where higher force application is required (Gottschall and Kram, 2005). More information and research on this variable are necessary to detect its capacity for identifying energy cost, as this calculation is optimal for team sports where the surface does not present changes in slope. In the present research it was not able to detect slope changes.

With respect to HR_{AVG}, the results showed great variability, with the highest values in uphill segments (DP1 = 191.1 ± 1.31 bpm; DP2 = 189.33 ± 1.70 bpm). All between-segment comparisons presented statistical differences ($p < 0.05$; $d = 0.52 - 2.05$), excepting the comparison between level segment 2 and downhill segment 2 ($p = 0.37$). These results are in contrast with Born, Stöggl, Swarén, and Björklund, (2017) where differences were not found in HR_{AVG} related to terrain slope, but were found in muscle oxygen saturation (SmO_2). On the other hand, the

HR results are similar to those obtained by Chatterjee et al. (2015). In this study slope changes directly affected VO_2 and cardiac output, with the highest values in uphill segments. Therefore, HR is a good indicator of physical intensity during a mountain running race, detecting with accuracy the high intensity of uphill segments, but not finding differences between level and downhill segments.

The velocities reached during the race were also variables related to the terrain slope, being greater in level segments. The differences between uphill and level segments, as found in previous research (Born et al., 2017; Chatterjee et al., 2015), are due to greater energy demands and higher oxygen uptake to maintain the same intensity. On the other hand, the speed decrease in downhill segments with respect to level segments has been related to the runner’s technical abilities and the terrain slope (Kay, 2014). Regarding ApEn, the variable that analyses signal complexity with respect to accelerometer raw data, results show differences among segment slopes but these differences were not significant.

Finally, regarding muscle stiffness (K_{VERT}), the lowest values were found in uphill segments compared to the rest of the segments, showing significant differences. The results obtained are related to the study by Giovanelli et al. (2016) who found a decrease in maximum force application in uphill segments, that directly affects K_{VERT}. Differences were also found between level segments and downhill segments that could be affected by the accumulated fatigue during the competition. Vernillo et al. (2015) showed that the energy cost at the end of races increases in downhill slopes due to a shorter flight time and a higher number of steps, demonstrating a lower capacity for force application.

CONCLUSIONS

1. External and internal load are significantly different during mountain running races because of the slope influence on the different segments.
2. An uphill slope provokes a greater internal load as recorded by HR_{AVG}, while level segments provoke greater external load as recorded by PL/min, MP/min and K_{VERT}. The fastest speed is found in level segments.
3. The velocity and external load variables recorded (MP/min, PL/min and K_{VERT}) showed similar behaviour in the analysed segments.
4. PL/min and K_{VERT} were found to be the most accurate variables to detect mountain running load demands due to their high sensitivity to identify the different types of slope (uphill, downhill or level).

PRACTICAL APPLICATIONS AND FUTURE RESEARCH PROPOSALS

The use of inertial measurement systems (IMUs) could give a more accurate perspective of load demands during trail running, thanks to the variables registered by these devices that are representatives of slope changes in mountain races. Using these data, specific training plans could be designed related to competition load demands to enhance performance and avoid injuries and overtraining.

The lack of research about this topic and the difficulties in quantifying training sessions due to the terrain slope and the variability of mechanical and physiological demands, makes it necessary to increase studies on this sports discipline. Future research should continue this type of analysis modifying the slope order, and the slope level to determine their effect on performance. Moreover, it seems necessary to analyse a greater number of participants and competitions, with the aim of comparing both within- and between-subject load demands.

Finally, also it would also seem necessary to increase scientific evidence about the influence of fatigue, dehydration, ambient temperature, and neuromuscular load, among other conditions present in these ultra-endurance disciplines on external and internal load variability.

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