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Anthropometric Characteristics, Training Intensity Distribution, Physiological Profile and Performance of an Elite Trail Runner: A Longitudinal Case Study

Características Antropométricas, Distribución de la Intensidad del Entrenamiento, Perfil Fisiológico y Rendimiento de un Corredor de Montaña de Élite: Un Estudio de Caso Longitudinal

Tomás Rivera-Kofler[1]; Rodrigo Soto-Lagos[2]; Carlos Herrera-Amante[3,4,5];
Guillermo Cortés-Roco[6]; Jorge Olivares-Arancibia[7]& Rodrigo Yáñez-Sepúlveda[8]

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SUMMARY: Trail running (TR), an extreme endurance sport, presents unique challenges due to the variety of terrain and distances, where physiological capacity and body composition have been considered better predictors of performance. This longitudinal case study examines the impact of training intensity distribution (TID) on an elite trail runner's physiological profile and performance over four years. Two TID models were implemented: polarized (POL) and pyramidal (PYR). Physiological assessments included maximal oxygen consumption (VO2max), lactate thresholds (LT1 and LT2), and anthropometric characteristics. The training was classified according to the 3-zone intensity model (zone 1: below the first lactate threshold; zone 2: between the first and second lactate threshold; zone 3: above the second lactate threshold). During the four years, the average TID distribution was 75 % zone 1, 18 % zone 2, and 7 % zone 3. Physiological capacity increased by 7.14 % (14 to 15 km/h) for velocity at LT1 (vLT1) and 8.13 % (16 to 17.3 km/h) for velocity at LT2 (vLT2). The most significant increases were observed during the second year when the percentage of training time in zone 1 was lower (65 %) and in zone 2 greater (30 %) than those reported in other years. Consequently, vLT1 and vLT2 increased by 3.5 % (from 14.1 to 14.6 km/h) and 3.6 % (from 16.5 to 17.1 km/h), respectively. In conclusion, this case study revealed that emphasizing training in zone 2 (moderate intensity) and increasing the training load significantly improved performance at lactate thresholds. Despite modifying body composition, no influence on improving endurance performance was observed. These findings underscore the importance of TID in elite trail runners and highlight the potential to optimize physiological adaptations and performance outcomes.

KEY WORDS: Trail Running; Training Intensity Distribution; Exercise Physiology; Body Composition Assessments; Sport Performance.

INTRODUCTION

Trail running (TR) is a physically demanding sport conducted on off-road trails, frequently in mountainous regions, with less than 20 % of the total race duration occurring on asphalt roads (Scheer *et al*., 2020). Distances in trail running can span from relatively short (< 42 km) to ultramarathon lengths (> 100 km), making it one of the most extreme forms of endurance sports (Ehrstrom *et al*., 2019; Doucende *et al*., 2022). The significance of studying trail running lies in its status as a multifaceted, physically demanding and extreme form of endurance sport (de Waal., *et al*., 2021).

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[1] Escuela de Educación. Carrera de Entrenador Deportivo. Universidad Viña del Mar, Chile.
[2] Management and Public Policies Department Faculty of Administration and Economics. University of Santiago of Chile (USACH), Chile.
[3] Nutritional Assessment and Nutritional Care Laboratory (LECEN), Division of Health Sciences, Tonalá University Center of Guadalajara, Tonalá, México.
[4] Ibero-American Network of Researchers in Applied Anthropometry (RIBA2), Almería, Spain.
[5] Research Division, Ibero-American Institute of Sports Sciences and Human Movement (IICDEM), Guadalajara, México.
[6] Escuela de Educación. Pedagogía en Educación Física. Universidad Viña del Mar, Chile.
[7] Grupo AFySE, Investigación en Actividad Física y Salud Escolar, Escuela de Pedagogía en Educación Física, Facultad de Educación, Universidad de las Américas, Santiago, Chile.
[8] Facultad de Educación y Ciencias Sociales. Universidad Andres Bello, Viña del Mar, Chile.

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Traditionally, distance running performance is associated with three key physiological variables: maximum oxygen uptake (VO2max), the energy cost of sport-specific movement patterns (i.e., running economy), and the fraction of VO2max that can be sustained during exercise, often related to physiological thresholds like ventilatory or lactate thresholds (Pate & Branch, 1992; Jones & Carter, 2000; Alvero-Cruz *et al*., 2020; González-Ravé *et al*., 2021; Campos *et al*., 2022). However, there remains a lack of consensus on which physiological factors primarily influence endurance performance in trail running. Some studies emphasize VO2max, lipid utilization, and muscular strength as predictors for short-term trail performance, while long-distance events appear to correlate with VO2max, body composition, muscular strength, and nutritional/hydration status (Ehrstrom *et al*., 2019; Belinchón-de Miguel *et al*., 2021; Pastor *et al*., 2022).

Training programs play a pivotal role in developing these physiological variables to enhance running performance. Consequently, the volume and training intensity distribution (TID) have emerged as critical factors in the success of endurance athletes (Seiler & Kjerland, 2006; Campos *et al*., 2022). TID involves dividing training zones based on physiological thresholds, encompassing low-intensity training (LIT) below the first threshold (Zone 1), moderate-intensity training (MIT) between the first and second thresholds (Zone 2), and high-intensity training (HIT) above the second threshold (Zone 3) (Seiler & Kjerland, 2006; Seiler & Tønnessen, 2009; Stöggl & Sperlich, 2015). In connection with this, recent literature has shown three primary TID models based on training intensity distribution: Polarized training (POL) characterized by accumulating ~75-80 % of training volume in Z1, ~5 % in Z2, and ~15-20 % in Z3 (i.e., Z1>Z3>Z2) (Treff *et al*., 2019). Threshold training (THR), characterized by the accumulation of training volume in Z2, ~45-50 % of training volume in Z1, ~45-50 % in Z2, and ~5-10 % in Z3 (i.e., Z1≥Z2>Z3) (Neal *et al*. 2012; Stöggl & Sperlich, 2015) and pyramidal training (PYR) distinguished by accumulating the highest percentage of training volume in Z1 (i.e., ~70 %) and correlatively decreasing in Z2 and Z3 (i.e., ~20 % and ~10 %, respectively) (Treff *et al*., 2019; Filipas *et al*., 2022).

While existing literature comprehensively documents TID models used by elite distance runners, cyclists, and swimmers, research on professional trail running is somewhat limited. This study aims to bridge this gap by providing a long-term analysis (> 1 year) of periodization strategies employed by elite trail runners to enhance their personal best performances. Consequently, this case study sheds light on the training characteristics of a successful elite trail runner, including training intensity distribution, volume, physiological data, body composition changes, and trail running performance over a 4-year periodization.

MATERIAL AND METHOD

The current data corresponds to the period from January 2019 to January 2023. The athlete described in this case was a 31-year-old male trail runner. The participant won the Chilean championship of the discipline in 2021 and 5th place in the South American trail running championship in 2022. In addition, the athlete was classified as elite according to the classification framework in sports and scientific development from McKay *et al*. (2022). The physiological and anthropometric characteristics of the athlete were: estimated maximum oxygen consumption (VO_{2max}), 68.9 ml.kg-1. min-1; body mass, 62.2 kg; body height, 172 cm; body mass index, 21.0 kg m-2. All procedures performed received institutional ethical approval according to the Declaration of Helsinki (World Medical Association, 2013). Furthermore, after explaining the objectives and practices, the athlete gave verbal and written consent to participate in the study.

The training intervention variables reported were volume (h/year), distance (km/year), distance climbed (m/year), and internal training load according to TRIMP score (Foster *et al*., 2001). The reported variables outcomes were velocity at the first and the second lactate threshold (vLT2 and vLT2, respectively), heart rate at the first and the second lactate threshold (HR-LT1 and HR-LT2, respectively), the average velocity in the 6-minute maximal running test (t-6 min), and the anthropometric profile; the athlete also reported endurance trail running performance.

Assessments. The assessments were carried out during weeks ~6-8 each year on two days separated by 48 hours. The athlete reported to laboratory following 24 hours of low exercise, diet control, and abstaining from caffeine and alcohol. All tests were performed under similar conditions (temperature 13-21º) and at the same time of day (09 00 – 11 00 h) to control the effects of circadian rhythms on physical capacity.

Body composition: On the first day of testing, anthropometric measurements were performed following the protocols suggested by the International Society for Advancement on Kinanthropometry (ISAK) (Ross *et al*., 1991) by an ISAK-certified researcher. The Heath and Carter model was used to calculate and classify the somatotype (2002). The components of body composition (muscle and fat mass) were calculated based on the model proposed by Kerr (1988).

Physiological capacity: A discontinuous incremental running test was conducted on a treadmill to assess the blood lactate profile. The test consisted of completing stations of 3 minutes each, which interfered with a 30-second pause to analyze capillary blood from the earlobe (Lactate pro 2 Arkay KDK, Kyoto, Japan). The test began at 10 kilometers per hour (km/h) with a 1 % slope, increasing the load by 1 km/h. Thirty seconds before the end of each 3-minute station, heart rate (HR; Polar Electro, Kempele, Finland) and rate of perceived exhaustion (RPE 1, 10) (Foster *et al*., 2001) were recorded. The test finished when a lactate of 4 mmol-L or higher was detected. The first (LT1) and the second (LT2) lactate thresholds were determined by the lactate concentration [La+] as previously suggested (Faude *et al*., 2009) and associated with heart rate (HR), velocity and RPE score to prescribe training intensities (Stoogl *et al*.,2015).

Cardiorespiratory and performance measures: On the second testing day, a 6-min running maximal test (t-6 min) was performed on a 400-m running track to predict maximal aerobic speed (MAS) and VO_{2max} calculated through the validated Bergman formula (Bergman *et al*., 2017). The evaluation began with a standardized warm-up consisting of 10 min of running at 10 km/h and 5 min of specific activation exercise. The athlete was instructed to cover the maximum distance possible during the 6-min duration of the test. With the distance covered in t- 6 min, the body mass index (BMI) and sex, VO_{2max} was obtained through the following equation (Bergmann *et al*., 2014).

VO_{2max} (mL Kg-1 min -1) = 41.946 + 0.022 * t-6 min - 0.875 * BMI + 2.107 * sex)
Meters for t-6 min and kg/m^2 for BMI. Female sex equals = 0; male sex equals 1.

Training intensity distribution: A model based on the results of the blood lactate profile was prescribed according to the three intensity zones (Stoogl *et al*.,2015). In addition, this model was used to quantify the training intensity distribution.

Zone 1 (LIT), HR and velocity below LT1; RPE < 4
Zone 2 (MIT), HR and velocity between LT1 and LT2; RPE > 4, < 7
Zone 3 (HIT), HR and velocity above LT2; RPE > 7.

Internal training load: To calculate internal training load, we analyzed HR via the training impulse model (TRIMP score). In this method, time (in minutes) in each training intensity zone (h-based time) was multiplied by the weighting factors 1, 2, and 3, respectively. Finally, obtain the total internal load of TRIMP by calculating the full scores of the three zones.

Training Intervention. According to physiological data, his coach (TR) prescribed the training program based on time goals to track each zone's time and control the internal training load. Thus, HR and rating of perceived exertion (RPE) scale were mainly used to define low-intensity training (i.e., zone 1). Velocity and RPE scales were also used to control moderate and high-intensity training (i.e., zone 2; zone 3). HR and RPE scale prescribed uphill training sessions when moderate and high intensity is the focus (i.e., zone 2; zone 3). The athlete recorded all training sessions with his HR monitor (HR; Polar Electro, Kempele, Finland) and then uploaded his data to specific analysis software (Training Peaks®, United States).

RESULTS

Throughout 4-years, the athlete covered a distance of 16.945 km and climbed 82.404 m. An average training week consisted of 8 sessions, with the maximal weeks consisting of 10 training sessions with a time of 14h. In addition, the athlete also completed weight training sessions in the second and third years; those that were separated total time dedicated to training. According to the 3-zone intensity model calculated TID via the heart-rate time-in-zone, the intensity distribution in the four-year periodization was 75 % zone 1, 18 % zone 2, and 7 % zone 3. Regarding training volume, no significant difference was found for the average weekly training time between the four years investigated (325 h for 1st, 339 h for 2nd, 300 h for 3rd, and 323 h for 4th year, respectively). However, a significant difference was found between the percentage of time spent in zones 1, 2, and 3 used in the different years. Figure 1 shows the TID over the four years investigated. Concerning the training load, the athlete average weekly TRIMP scores during the 2nd year were significantly higher than those registered during the 1st, 3rd, and 4th years, respectively.

Physiological and Performance Data. During the investigation, the performance capacity in the discontinuous incremental running test increased by 7.14 % (14 to 15 km/h) for vLT1 and 8.13 % (16 to 17.3 km/h) for vLT2. Another observed variable, the measurement of HR, presented a significant variation in HR-LT1 - 6,79 % (162 to 151 bmp) but did not show a significant variation in HR-LT2, 0 % (172 to 172 bmp).

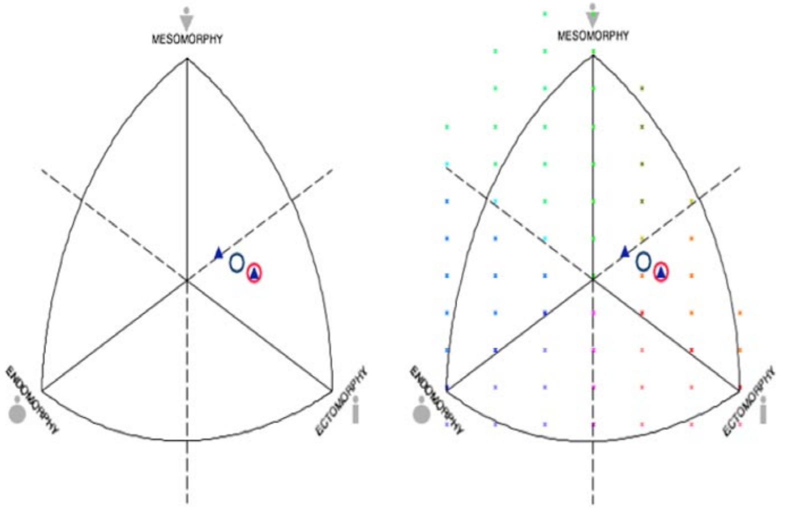
In the 6-minute running maximal test, VO2max increased by 1.92 % (67.6 to 68.9 mL·Kg-1), and predicted MAS increased by 2.69 % (18.9 to 19.4 km/h).

A POL training model characterized the 2019-20 period. During this year, 92.3 % of total training time was covered in zone 1, 2.7 % in zone 2, and 5 % in zone 3.

Variable	2019/2020	2020/2021	2021/2022	2022/2023
TID% h year (Z1, Z2, Z3)	92/3/5	65/30/5	84/13/3	85/13/2
Volume (h x year)	325h49min506s	339h29min27s	300h56min24s	323h59min52s
Distance (km year)	3865	3855	3450	2752
Distance climbed (m year)	30612	17556	18600	15636
TRIMPS (year)	21980	29812	27729	23888
vLt1 (km/h)	14.0	14.1	14.6	14.7
v Lt2 (km/h)	16.0	16.5	17.1	17.3
Hr Lt1 (l/min)	162	156	153	151
Hr Lt2 (l/min)	172	177	168	172
VO2max (ml/Kg/min)	67.6	70.0	69.2	69.2
MAS(km/h)	18.9	20.0	19.6	19.5

Fig. 1. Shows the results of the four incremental and performance running tests used to set training intensity zones.

Performance capacity in the discontinuous incremental running test changed by 0.7 % (14 to 14.1 km/h) for vLT1 and by 3.1 % (16 to 16.5 km/h) for vLT2. In contrast, the estimated VO_{2max} and MAS increased by 3.5 % (67.7 to 70 mL·Kg-1) and 5.8 % (18.9 to 20 km/h), respectively. During the 2020-21 period, the PYR training method was reported. This year, the percentage of training time in zone 1 was lower (65 %), and in zone 2 higher (30 %). Consequently, vLT1 and vLT2 increased by 3.5 % (from 14.1 to 14.6 km/h) and 3.6 % (from 16.5 to 17.1 km/h), respectively. However, VO2max and MAS decreased by -1.1 % (70 to 69.2 ml·Kg-1) and -2 % (20 to 19.6 km/h), respectively. The years 2021-22 and 2022-23 were also characterized by the use of the PYR model to distribute training intensity. However, the percentage of training time in the zones differed from the 2020-21 year. Here, the training time in zone 1 was higher (84 %) and zones 2 and 3 lower (12 and 3 %, respectively). Globally, when comparing the results from 2019 to 2023, substantial changes in physiological variables and sports performance are observed (Fig. 1).



2019: 1.2-2.8-4.0 (meso ectomorph) 2023: 1.9-3.3-3.2 (mesomorph - ectomorph) SAD: 0.6

Fig. 2. Somatotype classifications and migration from 2019 to 2023.

Somatotype and Body Composition. Figure 2 shows the somatotype of the year 2019 and that of the year 2023. There is an increase in endomorphy (0.7 points) and mesomorphy (0.5 points) and a decrease in ectomorphy (0.8 points), the classification changes from meso ectomorph to mesomorph – ectomorph. The somatotype distance (SAD) considering the three dimensions was 0.6 points.

Figure 3 shows the changes in somatotype from 2019 to 2023, highlighting the increase in body weight (3.4 kg increase), the sum of 6 folds increased from 30mm to 40mm, the percentage of muscle mass went from 18.7 to 21.4 % - 10.9 to 13.31 kg and muscle mass went from 48.2 to 46.2 % - 27.9 to 29.9 kg.

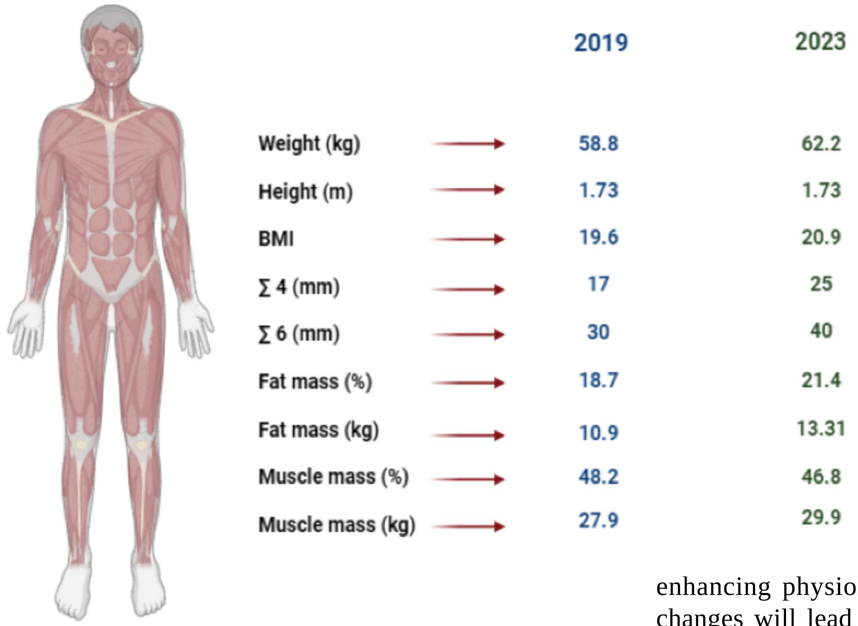


Fig. 3. Migration body composition from 2019 to 2023.

DISCUSSION

This study presents the anthropometric, physiological, and performance changes during a 4-year periodization in an elite trail runner. The athlete reported a training volume of ~300 to 339 hours per year, values lower than those presented by world-class long-distance runners (Casado *et al*., 2022; Hauggen *et al*., 2022). However, despite the low volume covered, positive changes in physiological capacity (i.e., lactate thresholds) were documented throughout the investigation. Consequently, these positive changes were related to the training intensity distribution, specifically to the effect of the PYR training model, where a high percentage of the training volume (30 %) was performed in the lactate accommodation zone (i.e., zone 2). These results are essential because lactate thresholds are one of the best predictors of long-distance performance (Bassett Jr. & Howley, 2000). In this sense, by exceeding the exercise intensity in velocity reached at the LT2 (i.e., vLT2), the predominance of anaerobic carbohydrate metabolism increases, producing a high release of H+, leading to a decrease in pH. This process contributes to the appearance of muscle fatigue, so performance is negatively affected (Huerta Ojeda *et al*., 2020).

For this reason, scientists widely agree that an increase in vLT2 typically results in improved endurance performance (Midgley *et al*., 2007). In this regard, the results of the research developed by Scheer *et al*. (2019), demonstrate that the blood lactate profile obtained in laboratory measurements with a discontinuous incremental running test can not only be used to predict performance in road races, these measures can be an excellent method to predict TR performance. These results demonstrate the importance of an “acceptable value” of lactate thresholds in trail runners and, consequently, the physiological support for using these variables to define training intensity, design training plans and enhance TR performance.

Several studies have attempted to identify which training methods are most effective for enhancing physiological capacity, assuming that these changes will lead to changes in endurance performance (Tanaka & Seals, 2008) In this sense, the POL and PYR models have reported more significant improvements and physiological adaptations in endurance athletes (Stoogl *et al*., 2015; Kenneally *et al*., 2018; Selles-Perez *et al*., 2019; Casado *et al*., 2022; Filipas *et al*., 2022). Both models have in common a high percentage of time performed at an intensity lower than the first physiological threshold (zone 1), where continuous high-volume, low-intensity sessions are completed. However, the analyses of the physiological capacity of our athlete throughout this research report a notable increase in vLT1 and vLT2, especially during the second year (2020-21), in which the percentage of training time in zone 1 was lower and greater emphasis was placed on training time within the zone of lactate accommodation (i.e., zone 2). Furthermore, a radical increase in the prescription of total internal training load according to the TRIMP score was observed. Despite the high training load and percentage of training time in zone 2, our athlete achieved his best TR performance, winning the 2021 discipline championship at the end of this period. This fact is essential because our results differ from those reported in previous studies in which successful performance is attributed to the accumulation of a large volume of LIT (zone 1) equal to or less than the workload at the first physiological threshold of intensity (Esteve-Lanao *et al*., 2007; Treff *et al*., 2017; Campos *et al*., 2022).

Concerning cardiorespiratory parameters, we found that the mean VO2max did not change during the investigation (1.9 %). In this context, the VO2max values obtained for our athlete were compatible with those reported for individuals classified as elite athletes (Mckay *et al*., 2022). Previous studies developed by Laursen & Jenkins

(2002), have already shown that changes in VO2max do not occur when elite athletes increase the volume or intensity of their training. Consequently, the magnitude of change after a training intervention was not surprising because modifications on this variable are dependent on the athlete's fitness level and initial VO2max. However, changes in submaximal exercise HR, specifically HR-LT1, reported a positive endurance training adaptation. This variable was significantly reduced (-6.79 %) during the four years investigated. The main reason behind these findings may be related to the fact that long-term endurance training significantly induces physiological modification affecting the autonomic nervous system by decreasing sympathetic activity to the heart (Carter *et al*., 2003).

Regarding the influence of our runner's anthropometry on his aerobic performance, we did not find a positive relationship between the anthropometric variables investigated and improved physiological capacity. However, based on the findings of previous research, these variables are the most critical factors related to half marathon performance, and the half marathon race time is considered a key predictor of TR race performance (Knechtle *et al*., 2012; Gómez-Molina *et al*., 2017). In another investigation but carried out with male ultra-endurance runners, Knechtle *et al*., 2010, found that none of the anthropometric variables studied were related to the total running time, suggesting that training and intensity could be of greater importance in improving performance when compared with anthropometry. Based on the above, it is relevant to consider that small changes in body composition may not negatively influence performance when the periodization of training generates physiological and enzymatic adaptations, this being a more important determinant of performance than small changes in body composition.

Our study presents several limitations that may affect the quality of this investigation:

1. VO_{2max} was not determined based on gas exchange parameters using indirect calorimetry. Consequently, the energy cost of sport-specific movement patterns (i.e., the economy of movement in units of milliliter of O2/kg/km) considered one of the critical endurance performance-related variables could not be investigated.

2. TR performance assessment was carried out by monitoring the physiological capacity in the laboratory and with indirect track tests (t 6-min). Therefore, it is easier to draw specific conclusions about improvements in performance in TR with a trail-specific testing protocol.

3. We do not report monitoring heart rate variability (HRV). Therefore, we could not investigate the effects of prolonged endurance training on the autonomic activity of the heart. HRV monitoring has been proposed as a critical variable to effectively balance training stimuli's positive and negative effects (Seiler *et al*., 2007).

In summary, physiological regulation plays a crucial role in adapting training programs (Düking *et al*., 2021). For this reason, it is necessary to know the effectiveness and safety of the different models of TID, the most appropriate percentage of volume in each zone, and the use of HRV to organize such distribution.

CONCLUSION

Maximizing the adaptations that endurance training promotes is a consequence of many variables. However, training intensity distribution is one of the most important factors, especially considering the training volume in each zone. In this sense, this research confirms that the prescription of a considerable percentage of annual training time in zone 2 was positively correlated with positive changes in physiological capacity (vLT1 and vLT2). Furthermore, when training volume is limited by time capacity, increases in total internal training load may be considered one of the most essential elements in promoting greater performance in endurance athletes. Finally, despite modifying body composition and somatotype migration, no influence on improving endurance performance was observed. This suggests these variables do not generate adverse effects when the training methods meet the objective.

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RESUMEN: Trail running (TR), un deporte de resistencia extrema, presenta desafíos únicos debido a la variedad de terrenos y distancias, donde la capacidad fisiológica y la composición corporal se han considerado mejores predictores del rendimiento. Este estudio de caso longitudinal examina el impacto de la distribución de la intensidad del entrenamiento (TID) en el perfil fisiológico y el rendimiento de un corredor de montaña de élite durante cuatro años. Se implementaron dos modelos TID: polarizado (POL) y piramidal (PYR). Las evaluaciones fisiológicas incluyeron el consumo máximo de oxígeno (VO2max), los umbrales de lactato (LT1 y LT2) y las características antropométricas. El entrenamiento se clasificó según el modelo de intensidad de 3 zonas (zona 1: por debajo del primer umbral de lactato; zona 2: entre el primer y segundo umbral de lactato; zona 3: por encima del segundo umbral de lactato). Durante los cuatro años, la distribución TID promedio fue 75 % zona 1, 18 % zona 2 y 7 % zona 3. La capacidad fisiológica aumentó un 7,14 % (14 a 15 km/h) para la velocidad en LT1 (vLT1) y un 8,13 % (16 a 17,3 km/h) para velocidad en LT2 (vLT2). Los incrementos más significativos se observaron durante el segundo año cuando el porcentaje de tiempo de entrenamiento en la zona 1 fue menor (65 %) y en la zona 2 mayor (30 %) que los reportados en otros años. En consecuencia, vLT1 y vLT2 aumentaron un 3,5 % (de 14,1 a 14,6 km/h) y un 3,6 % (de 16,5 a 17,1 km/h), respectivamente. En conclusión, este estudio reveló que enfatizar el entrenamiento en la zona 2 (intensidad moderada) y aumentar la carga de entrenamiento mejoró significativamente el rendimiento en los umbrales de lactato. A pesar de modificar la composición corporal, no se observó influencia en la mejora del rendimiento de resistencia. Estos hallazgos subrayan la importancia del TID en los corredores de trail de élite y resaltan el potencial para optimizar las adaptaciones fisiológicas y los resultados de rendimiento.

PALABRAS CLAVE: Trail running; Distribución de la intensidad del entrenamiento; Fisiología del ejercicio; Evaluaciones de composición corporal; Rendimiento deportivo.

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Corresponding autor:
Dr. Rodrigo Yáñez-Sepúlveda.
Facultad de Educación y Ciencias Sociales
Universidad Andres Bello
Viña del Mar
CHILE

E-mail: rodrigo.yanez.s@unab.cl