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Analysis of Trail Runner Performance Based on Coros Wearable Device Data

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Keywords

Trail Runn-ing, Pace, Heart Rate, Elevation

Abstract

This study analyzed the performance of an ultra-trail runner in two races (62 km and 50 km) using a wearable device (Coros Pace 3). The subject was a 26-year-old male runner with more than four years of experience in ultra-trail running. Parameters examined were pace, heart rate (HR), and elevation. The results showed that elevation strongly influenced both pace and HR, with more conservative pacing observed in the 62 km race and more aggressive early effort in the 50 km race. The analysis was conducted descriptively and through a regression model with elevation control as a covariate. The results showed an oscillatory pacing pattern influenced by elevation contours, with HR increasing significantly in uphill segments. These findings highlight the importance of adaptive pacing strategies based on elevation profiles and suggest that wearable data can provide practical insights for training and competition. Runners need to know the details of the race track, including distance and elevation, and train in conditions similar to the actual track so that physiological adaptations occur and they can achieve their best performance during the race.

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INTRODUCTION

Trail running is a long-distance discipline conducted on varied natural terrains, characterized by technical uphill and downhill routes. Unlike road running, trail running has specific characteristics, such as challenging terrain including rocky and sandy paths, hills, mountains, forests, and natural soil. These dynamic track conditions require athletes to monitor their performance to maintain both physical endurance and crucial mental resilience, especially during long-distance events (Rosenkrantz et al., 2024).

In the ultra-trail category, the distance covered is extensive. Generally, these runs exceed 50 kilometers and can reach several hundreds, involving significant elevation gain and challenging terrain. Some ultra-runs are even held in extreme environments like deserts, such as the Samla race in 2023 (Esh et al., 2025). Ultra-trail running demands not only endurance and mental strength but also logistical preparation and problem-solving skills, as participants frequently face weather changes and fluctuating terrain (Haugen et al., 2022). During competition, participants must monitor their physiological state, such as heart rate, in real-time to optimize their effort toward the finish line.

When participating in a trail run, individuals can track their heart rate, pace, and elevation in real-time using various wearable devices (Janssen et al., 2017). This study focuses on Coros wearables, which are designed to calculate pace, heart rate (HR), and elevation during competition. Wearable technology enables objective data collection and provides insights into runners' physiological responses to terrain changes that are difficult to measure using conventional laboratory methods (Lampa et al., 2025). Runners who monitor their real-time data can maintain optimal physical condition (Navalta et al., 2020).

Real-time studies, particularly single-subject designs, are crucial because each athlete exhibits unique physiological responses and speed dynamics. For example, research on elite marathon runners shows that individual speed oscillations can significantly affect finish times (Pycke & Billat, 2022). While previous studies, such as Thornton (2023), have reviewed general pacing strategies, and Takayama & Miyazaki (2022) examined physiological responses in a single 168-km race, there is a lack of comparative data analyzing how a single runner adapts their physiological and pacing dynamics across different ultra-trail distances with high elevation gain. Literature analyzing single-subject performance during competition remains limited, especially regarding the comparison of multiple races with varying profiles.

This approach is essential because of each runner's unique physiological characteristics and adaptation strategies (Lempke et al., 2023). By integrating the relationship between pace, heart rate, and elevation per kilometer, this study provides a comprehensive understanding of pacing strategies. Therefore, this research aims to analyze the performance dynamics of ultra-trail running across two competitions of different distances (62 km and 50 km) using wearable data. This analysis is expected to provide insights into the relationship between physiological variables and trail conditions, informing future competition strategies and training programs.

METHODS

This study uses a quantitative approach with a single-subject design to analyze performance metrics in ultra-trail running. Data were collected using a Coros Pace 3 (optical heart rate + GPS) with HR and GPS data downloaded at the default sampling rate. The data collection was carried out during two specific competitions in August 2025: a 62 km race with an elevation gain of 4,028 m and a 50 km race with an elevation gain of 3,942 m. To maintain data integrity, paces exceeding 15 min/km were annotated and treated as possible artifacts or aid station breaks.

The research procedure was carried out through several integrated stages in a narrative sequence. The first stage involved extracting primary data from a single runner through the Coros watch application. Secondly, the data was reviewed and categorized based on three main parameters: pace (min/km), heart rate (HR, bpm), and elevation gain per kilometer. The analysis was further divided into uphill, downhill, and flat segments based on a specific elevation change threshold of ±30 m per kilometer.

The final stage involved data processing using SPSS software. The analysis focused on pacing dynamics, physiological response (HR), and terrain adaptation. Data were processed using two main statistical methods: descriptive statistics to provide a general overview of the metrics and Pearson correlation to examine the relationship between variables. These methods were chosen to provide a comprehensive comparison between the two races and ensure that the performance dynamics were displayed clearly and could be described further for practical application in training and competition.

RESULTS AND DISCUSSION

This section provides a comprehensive overview of the metric results collected during the trail running events monitored using the Coros Pace 3 device. The data obtained allow for a detailed analysis of performance development throughout the competition, offering valuable insights into the runner's physiological and mechanical trends (Janssen et al., 2017).

The following analysis further explains the results and provides a scientific discussion regarding the integration of pace, heart rate (HR), and elevation. This explanation enables a deeper understanding of the strategies and actions required to optimize trail running performance. Below is a summary of the key metrics from both the 62-km and 50-km events, as recorded directly by the Coros device.

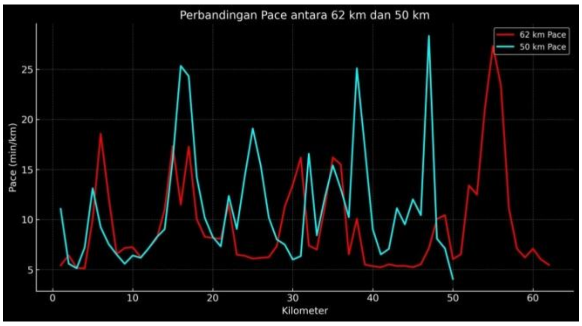

Figure 1. Comparison of pace between 62 km and 50 km races

In the 62 km race, there was significant pace variability with extreme slowdowns seen at kilometers 6–7, 15–17, 31–35, and 54–56, with pace slowing to over 20 min/km, largely due to significant elevation gain. Interestingly, the middle segment of the race (39–46 km) showed a recovery in performance with a stable pace in the range of 5:20–5:53 min/km. In contrast, in the 50 km race, the pace distribution was stable in the early kilometers, namely in the range of kilometers 2–4, 6–14, and in several other parts in the middle and end of the race. However, there were some sections where runners drastically slowed their pace, such as at kilometer 47, where the pace dropped to 28, allowing the runner's heart rate to decrease optimally and recover performance to reach the finish line with a pace in both events reaching 2 at the end of the time.

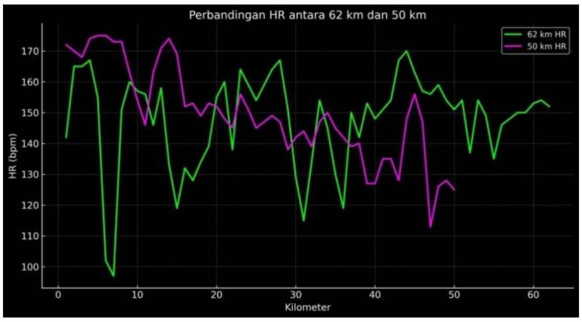

Figure 2. Comparison of heart rate (HR) between 62 km and 50 km races

The runner's heart rate shows that the 62km race started with an HR of 142bpm, but increased at kilometers 2-4 (165–167 bpm) and then decreased sharply at kilometers 6–7 (102–97 bpm). This can be seen from the runner drastically slowing down at an elevation of 308 meters at kilometer 6, with the runner's heart rate stabilizing again from that kilometer until the end of the race. For the 50km race, the runner had a high HR from the start, reaching over 170 from the beginning, marked by an elevation gain and loss of over 100 meters at the start. Runners can lower their HR again after passing kilometer 9, based on data showing that the elevation drops significantly, allowing runners to be assisted by downward gravitational pull, eliminating the need for extra effort and enabling them to complete the race (Sanchez et al., 2025).

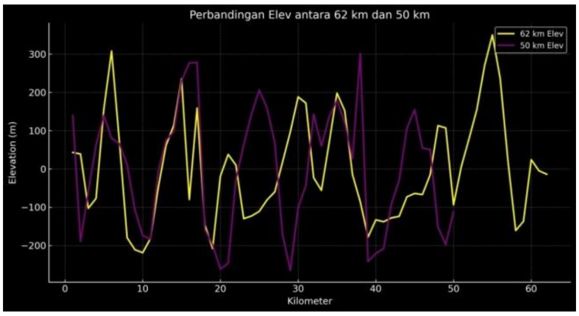

Figure 3. Comparison of heart rate (HR) between 62 km and 50 km races

Both races have similar elevation gains of 62 km (4,028 m) and 50 km (3,942 m). These two factors determine how high the HR and pace slowdown will be over several kilometers, for example in the 60 km race which includes large climbs (km 5: +156 m; km 6: +308 m; km 15: +235 m; km 54–56: +270–350 m) and sharp descents (up to −219 m), causing fluctuations in pace and HR. In the 50 km race, the elevation challenge occurs in the middle of the race (km 15–17: +230–278 m; km 38: +301 m) and steep descents at km 20–21 (−246 to −262 m). For the continuation of the second data, we can make a descriptive statistical analysis with its correlation with the following description.

Table 1. Descriptive statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Pace 62	63	2.39	27.33	9.3430	4.90027
HR 62	63	97.00	170.00	147.8730	15.27014
Elevation 62	63	-219.00	350.00	.0794	136.63907
Pace 50	51	2.30	28.34	10.8939	5.69026
HR 50	51	113.00	175.00	149.6471	15.35295
Elevation 50	51	-265.00	301.00	-.0784	158.12942
Valid N (listwise)	51				

The table above shows the mean and standard deviation (Mean ± SD) of the runners' performance variables during the 62 km and 50 km races. In general, the average speed (pace) in the 62 km race was faster (9.34 min/km) than in the 50 km race (10.89 min/km), although both had quite high variations (SD > 4). The average heart rate was relatively similar between the two races (147.9 vs. 149.6 bpm), indicating consistency in cardiovascular load. Elevation differences were fluctuating, with large variations in both races (SD > 130 m), indicating challenging terrain and contributing to changes in pace and runners' physiological responses. Slower average pace in the 50 km race, slightly higher HR, and very large elevation variations in both races.

Table 2. 62 km Race

Correlation	r	Sig. (p)	Interpretation
Pace ↔ HR	-0.62	<0.001	Strong negative correlation (the faster the pace → the higher the HR)
Pace↔ Elevation	0.81	<0.001	Very strong positive correlation (pace slows on inclines)
HR↔ Elevation	0.50	<0.001	Moderate-strong negative correlation

Table 3. 30 km Race

Correlation	r	Sig. (p)	Interpretation
Pace ↔ HR	-0.22	0.129 (ns)	Weak correlation, not significant
Pace ↔ Elevation	0.60	<0.001	Strong positive correlation
HR ↔ Elevation	0.30	0.030	Weak to moderate correlation, significant

The table above shows that races 62 and 50 km have several differences in data presentation, ranging from strong to weak correlations. Below is an explanation of how to read both sets of data.

62 km Race

1. Elevation greatly affects pace (r=0.81), meaning that extreme inclines/declines really slow down speed.
2. HR correlates negatively with pace (r=-0.62), in line with physiology: when pace is faster, HR increases.
3. HR also correlates negatively with elevation (r=-0.50), possibly because pace slows down drastically on inclines, so HR does not rise as high.

50 km Race

1. Elevation still has a strong effect on pace (r=0.60), consistent with the 62 km race.
2. The HR–Pace correlation is weak and insignificant, indicating that fatigue or pacing strategy is more decisive than heart response.
3. HR–Elevation shows a weak positive correlation (r=0.30), indicating an increase in HR on inclines, unlike the 62 km race.

It can be described that the comparison between the two races can be seen starting from the 62 km race, where cardiovascular response (HR) is clearly related to performance (pace and elevation). In the 62 km race, runners maintained an average pace of 9.34 ± 4.90 min/km with a HR of 147.9 ± 15.3 bpm. In the 50 km race, the average pace was 10.89 ± 5.69 min/km with a HR of 149.6 ± 15.4 bpm. Segmental analysis showed the highest HR in the uphill segment (average 156 bpm), while the most consistent pace was seen in the flat segment. In the 50 km race, HR is not very consistent with pace, because the race is shorter so athletes are able to maintain intensity with different strategies. In general, elevation is the dominant factor affecting performance in both races. The data also shows that the 62 km race favors a conservative pacing strategy, as indicated by a lower and more stable HR (~150–160 bpm) despite the longer distance. This strategy allows runners to recover their performance in the middle segment of the race(Bossi et al., 2016). Conversely, the 50 km race featured an aggressive strategy at the start (high HR from km 1), which led to earlier fatigue and a decline in performance sustainability.

This conservative pacing strategy is consistent with literature showing that the fastest runners tend to "slow the least" and have a more even pace throughout the race, while slower runners experience a drop in pace of up to 40% in the final stages of the race (Thornton, 2023).

However, in addition to relying solely on pacing strategy, we must also consider the elevation profile, which has been proven to be a dominant factor in determining the dynamics of the race. At 62 km, a significant climb towards the end of the race is associated with extreme pace slowdowns. At 50 km, the main elevation challenge arises in the middle of the race. A longitudinal study of the Western States Endurance Run (a famous ultramarathon) shows that pacing is greatly influenced by elevation, and shows positive pacing (slowing down progressively), with the fastest runners showing lower pacing variability (Bennett & Cary, 2024).

(Markovic et al., 2025) Ultimately, the best strategy for ultra-distance races is to pace yourself from the start and be aware of the elevation profile so you can monitor your heart rate in real-hightime to ensure it doesn't get too high throughout the race and you can maintain it well until the end (Navalta et al., 2020). According to various studies and athletes' experiences, the best pacing strategy in ultra-trail is to maintain as steady a pace as possible (constant) throughout the race, starting with a slow tempo to conserve energy and avoid early fatigue, and adjusting effort according to terrain conditions through a combination of run-walk—running on flat and downhill sections and walking on uphill or technical sections (Moore & Nolan, 2020). Oscillatory pacing in ultra-runners is influenced by course contours. Elevation plays a significant role in HR and pace variations, suggesting the need for adaptive pacing strategies on uphill sections and efficiency on flat sections. Compared to similar studies on half-marathons, pace variability in ultra-trail runners is higher, but HR response patterns remain consistent. Limitations of this study include the use of a single sample and the inaccuracy of optical HR sensors at high intensities. Further research using chest strap sensors and more sophisticated time-series approaches is recommended.

CONCLUSION

This study highlights the role of wearable technology in analyzing trail running performance by comparing two ultra-distance races of 62 km and 50 km. The findings reveal that elevation is the most dominant factor influencing both pace and heart rate. In the 62 km race, a conservative pacing strategy with relatively stable heart rate allowed the runner to maintain performance despite longer distance and extreme terrain fluctuations. Conversely, in the 50 km race, the runner adopted a more aggressive start, reflected by higher heart rate from the beginning, which contributed to earlier fatigue and less sustainable pacing. The statistical correlations also confirmed that in the 62 km race, pace and heart rate had a strong inverse relationship, whereas in the 50 km race, the relationship was weaker and inconsistent. This suggests that adaptation strategies differ depending on race distance and elevation profile.

This study significantly contributes to the endurance sports literature by presenting an intra-individual comparative analysis rarely found in previous ultra-trail studies. Unlike conventional single-case studies that focus on a single race as an (Takayama & Miyazaki, 2022), this study successfully documents how the same subjects adapt their pacing strategies and physiological responses at two different distances (62 km and 50 km) with nearly identical elevation profiles in close time. These results also complement the theory of (Thornton, 2023) by providing empirical evidence based on wearable data (Coros Pace 3) that oscillatory pacing in ultra-runners is not solely determined by physical fitness, but is highly dependent on energy management based on real-time course contours. Practically, this study demonstrates that the use of wearable technology allows athletes to conduct highly granular performance audits, which can ultimately be used to design more precise elevation simulation-based training programs to optimize endurance efficiency. Overall, wearable data provides valuable insights into pacing dynamics, physiological adaptation, and the influence of terrain, which can be directly applied to training and competition strategies. For practical implications, runners are advised to simulate race conditions during training, especially focusing on elevation profiles, in order to optimize physiological adaptation and improve endurance efficiency. Future studies could expand this approach by involving multiple single-subject analyses to enrich the understanding of individual variability in trail running performance.

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