

Pacing Strategies of Ultrarunners under Extreme Weather Conditions Performed on Multiple Stages

by

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Pacing strategies are important factors for running performance and have been studied over the years. Nevertheless, whether the implementation of such strategies is crucial at ultramarathons under extreme weather conditions remains unclear. The purpose of this study was to investigate the use of running pace strategies in ultramarathons performed under very hot or cold weather conditions. Data from Desert Ultra 2022 and 2023 and Ice Ultra 2023 and 2024, each covering approximately 250 km during five consecutive days, were analyzed. Data from 143 runners included sex, finish time, pace, velocity, the number of runners who did not finish the ultramarathon, and the number of runners who did not start the ultramarathon. Participants were categorized into top 3, top 10, and top 20. Finish times were no equivalent between events (Ice Ultra; 43:47 ± 7:02 h:min vs. Desert Ultra; 48:10 ± 8:27 h:min; $p = 0.002$). The top 3 participants exhibited higher velocity in multiple stages compared with the other groups ($p < 0.01$). In top 20 runners, maintenance of the velocity pattern throughout the days was evident. However, the Ice Ultra group exhibited a decline in velocity between stages 1 and 2 (Δ top 3: 2.23 ± 0.14 km/h; Δ top 10: 2.11 ± 0.15 km/h; Δ top 20: 1.19 ± 0.18 km/h). Higher densities showed high heterogeneity among runners regardless of desert or ice running. Relief and weather are important factors in pacing strategies. Ice Ultra runners displayed a parabolic running strategy. In the Desert Ultra race, a substantial reduction in speed was observed even when there was no slope and even halfway through the completion of the pacing strategy stages. Managing fatigue from previous stages and temperature fluctuations are relevant factors that can be better explored.

Keywords: ultramarathon; athletic performance; extreme heat; pacing

Introduction

Ultramarathons comprise distances greater than 50 kilometers (km) or duration longer

than 6 hours (h) (Scheer and Krabak, 2021). These events can last for multiple days, often being held on trails, mountains, and roads which present different climates and temperatures (Waśkiewicz

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et al., 2019). Generally, ultramarathon performance involves several aspects related to both the runner and the environment (Hsu et al., 2022; Knechtle et al., 2019). Competitive strategies have been highlighted as important factors since results come from individual characteristics in response to situational factors (Casado et al., 2021a; Martínez-Navarro et al., 2021).

Competitive strategies include variation in power/velocity that occurs through an event, aiming to regulate energy expenditure for maximal efficiency to complete the event (Fernandes et al., 2015). Interest in this subject was initiated in the 1990s through research into understanding the different energy systems; however, knowledge regarding optimal strategies during medium-distance (1.5–2.0 h) and ultra-endurance (>4 h) events is lacking (Abbiss and Laursen, 2008). Some evidence suggests that in ultramarathons held in a single day, well-trained athletes progressively slow down after reaching maximum speed (Knechtle et al., 2015; Suter et al., 2020).

Amateurs and elite long-distance runners adopt different pacing strategies during long-distance competitions. Among the strategies used, parabolic “J” and “U” ones, with negative (increases in running velocity) and positive patterns (decreases in running velocity) (Casado et al., 2021b), have been the most used. Pacing strategies have been extensively studied in marathon races (García-Manso et al., 2021; Nikolaidis and Knechtle, 2018; Martínez-Navarro, et al., 2021; Sha et al., 2024; Weiss et al., 2024); however, only few studies have explored pacing strategies in ultramarathons (García-Manso et al., 2021; Nikolaidis and Knechtle, 2018). Evidence shows that a negative pacing profile was employed by elite runners in 100-km (Knechtle et al., 2015) and 161-km (Hoffman, 2014) races. Conversely, another study showed a stable pace adopted in a single-day 170-km race (Suter et al., 2020). In addition to the distance, performance can be influenced by environmental factors such as temperature, altitude, and the terrain type (Costa et al., 2014). Technological improvements (i.e., clothing, shoes) are fundamental safety items in ultramarathons. Moreover, hydration strategies (e.g., programmed fluid intake) when the event is held under extreme weather conditions, such as in the desert and snow, are of utmost importance.

Pacing strategies in ultramarathons under

extreme weather conditions require additional care. Previous studies have highlighted the detrimental effects of exposure to extreme temperatures (approximately 40°C or below 0°C) on the maintenance of prolonged exercise capacity (Bouscaren et al., 2021; Filep et al., 2020) and the potential development of physiological disorders (Bergeron, 2014; Hsu et al., 2022). Heat can culminate in severe heatstroke due to exertion, characterized by a core body temperature above 40.5°C (Bouscaren et al., 2019). These symptoms are associated with the dysfunction of the central nervous system, which can lead to delusions, convulsions, and a state of coma (Leon and Bouchama, 2015). In polar climates, adverse effects on the mood, sleep, and performance are well documented (Graham et al., 2020; Millet et al., 2011). Furthermore, in ultramarathons, increases in skin problems (33–74%) have been reported, including blister-related injuries (Krabak et al., 2011).

Moreover, in competitions held over multiple days with long daily routes, competitors can share experiences about the route and other indicators during meetings at night rest points to obtain information and anticipate adverse events. Relief, weather and altitude conditions are considered crucial factors for pacing strategies. These factors can have a significant impact on performance and dictate the pacing strategy used by ultra-marathon runners. Therefore, this study aimed to investigate the running pace strategies of ultra-marathoners participating in competitions held over five continuous days under extremely hot or cold weather conditions.

Methods

Participants

This study used data obtained through the analysis of individual results of 143 finalist runners of both sexes of the Desert Ultra 2022 (n = 46) and 2023 (n = 28) and the Ice Ultra 2023 (n = 30) and 2024 (n = 39) ultramarathons. The runners who completed all stages of the competitions were included in the present study, excluding subjects who did not finish (DNF) and did not start (DNS) the races. Since this study involved the analysis of publicly available data, the requirement for informed consent was waived; however, the study was approved by the ethics committee of the Federal University of Sergipe, São Cristóvão, Brazil

(approval code: CAAE 7061323.0.0000.5546; approval date: 08 February 2024). Data were taken from official digital platforms of the respective events at <https://beyondtheultimate.co.uk> (accessed on 20 February 2024).

Design and Procedures

An observational transverse study design was used. Data included sex, running time, running pace, and velocity. The considered ultramarathons were held in multiple stages with duration of five days under different extreme weather conditions. The Desert Ultra race took place in the Namib Desert covering a total course of approximately 250 km (50, 48, 43, 22, and 87 km) over dunes and dry riverbeds, with temperature variation from 35°C to 55°C during the day and 5°C to -10°C at night. The Ice Ultra race was held in Swedish Lapland, with a course of approximately 225 km (60, 44, 42, 64, and 15 km) in fields, forests, and mountains in snow and frozen rivers under thermal variation from 5°C to -40°C during the day and -10°C to -40°C at night. The stage details are shown in Figure 1. For comparative analysis, the runners were divided into the following three stratified groups categorized by performance: first three (Top 3), first ten (Top 10), and first twenty (Top 20) finishers.

Statistical Analysis

Descriptive (mean \pm standard deviation) analysis was conducted to present a basic description of participants (the number of finalists and pace). Running time and pacing were analyzed and stratified by stages and classifications (Top 3, Top 10 and Top 20). The normality of data distribution was verified through the Shapiro-Wilk test. An independent samples *t*-test was employed to compare events (Ice Ultra vs. Desert Ultra). For analysis between stages, two-way ANOVA was used (factors: competitions and stages), followed by the Bonferroni's post hoc test. The effect size was presented through partial square eta (η^2) and Cohen's *d*. Velocity differences (Δ values) for each runner along stages and performance groups (Top 3, Top 10, and Top 20) were calculated. Violin plots were used to present the variability within and between events over stages. Software used for analyses was Statistical Package for Social Sciences (SPSS), version 20®, and GraphPad Prism version 8.00, adopting a significance level of $p < 0.05$.

Results

The data showed a greater prevalence of participation of men over women: 61.76% vs. 38.23% and 73.91% vs. 26.08% in the Ice Ultra and Desert Ultra events, respectively (Figure 2b). For the total time of each race, significant differences were observed between the Desert Ultra (48:10 \pm 8:27 h:min) and Ice Ultra (43:47 \pm 7:02 h:min; $p < 0.002$) events (Figure 2a).

The pace of the Ice Ultra runners at point 2 (14:28 \pm 3:11 min/km; $p < 0.0001$) was slower when compared with point 1. At points 2 (14:28 \pm 3:11 min/km) and 4 (13:57 \pm 2:60 min/km), Ice Ultra runners were slower than Desert Ultra runners ($p < 0.0001$). Ice Ultra runners at point 5 (10:06 \pm 2:94 min/km) were faster than at point 4 (13:57 \pm 2:60 min/km; $p < 0.0001$). Both the Ice Ultra and Desert Ultra runners were slower at point 5 (13:00 \pm 2:60 min/km) than at point 4 (12:00 \pm 2:00 min/km; $p < 0.0001$) (Figure 2c). Finishers accounted for 69.0% of the Desert Ultra and 78.7% of the Ice Ultra runners (Figure 2d).

Analysis by ranking (Top 3, Top 10, and Top 20) of the Desert Ultra and Ice Ultra runners showed that the velocity of the Top 3 runners was higher across all stages ($p < 0.01$). The Top 10 runners were faster than those belonging to the Top 20 ($p < 0.01$) (Figure 3a and b).

Via the violin plot, analysis of intra- and inter-competition variability and their stages indicates that throughout all days, athletes showed a notably heterogeneous pacing behavior.

Table 1 presents the velocity differences (Δ values) along stages and groups (Top 3, Top 10, and Top 20). During the Ice Ultra event, from stages 1 to 2, a drop in velocity of 26.5%, 32.1% and 35.3% occurred in the Top 3, Top 10, and Top 20 groups, respectively, following an increase in velocity up to stage 5. During the Desert Ultra event, there was a significant reduction in velocity in stage 3 of 13.9% in the Top 3, 14.4% in the Top 10, and 14.03% in the Top 20 groups when compared with stage 1. The velocity of the Top 10 and Top 20 groups did not fluctuate significantly until stage 5.

Regardless of the group, a significant decrease in velocity occurred between stages 1 and 2 of the Ice Ultra event ($\Delta_{\text{top 3}}$: 2.23 \pm 0.14 km/h, $\Delta_{\text{top 10}}$: 2.11 \pm 0.15 km/h, and $\Delta_{\text{top 20}}$: 1.19 \pm 0.18 km/h), while the greatest increase occurred between stages 4 and 5 ($\Delta_{\text{top 3}}$: -1.92 \pm 0.23 km/h,

$\Delta_{top 10}$: -1.86 ± 0.24 km/h, and $\Delta_{top 20}$: -1.29 ± 0.13 km/h). In the Desert Ultra event, there was a significant decrease in velocity between stages 1 and 2 ($\Delta_{top 3}$: 0.63 ± 0.28 km/h, $\Delta_{top 10}$: 0.78 ± 0.29

km/h, $\Delta_{top 20}$: 0.62 ± 0.10 km/h), and the highest value of delta occurred between stages 3 and 4 ($\Delta_{top 3}$: -0.94 ± 0.26 km/h, $\Delta_{top 10}$: -0.50 ± 0.28 km/h, and $\Delta_{top 20}$: -0.26 ± 0.13 km/h).

Table 1. Velocity mean difference between stages. Data are presented by the event and the group.

Ice Ultra	Top 3				Top 10				Top 20			
Stage	Mean (Δ)	Cohen's <i>s d</i>	r	r ²	Mean (Δ)	Cohen's <i>s d</i>	r	r ²	Mean (Δ)	Cohen's <i>s d</i>	r	r ²
1-2	2.23 (0.14)	2.77	0.995	1.00	2.11 (0.15)	4.53	0.948	0.90	1.91 (0.18)	6.44	0.609	0.37
2-3	0.90 (0.22)	-0.99	0.977	0.95	-0.97 (0.20)	-2.31	0.913	0.83	-0.76 (0.29)	-2.55	0.639	0.41
3-4	-0.06 (0.32)	-0.07	1	1.00	-0.09 (0.14)	-0.28	0.916	0.84	-0.11 (0.15)	-0.60	0.906	0.82
4-5	-1.92 (0.23)	-2.50	1	1.00	-1.86 (0.24)	-5.16	0.777	0.60	-1.29 (0.13)	-1.45	0.925	0.86
Desert Ultra												
1-2	0.63 (0.28)	1.74	0.992	0.98	0.78 (0.29)	0.93	0.95	0.89	0.62 (0.10)	3.36	0.936	0.88
2-3	0.57 (0.14)	1.82	0.992	0.98	0.19 (0.33)	0.23	0.946	0.89	0.19 (0.07)	1.13	0.945	0.89
3-4	-0.94 (0.26)	-3.16	0.811	0.66	-0.50 (0.28)	-0.72	0.922	0.85	-0.26 (0.13)	-1.18	0.83	0.69
4-5	0.91 (0.25)	2.99	0.859	0.74	0.62 (0.34)	-1.79	0.87	0.76	-0.29 (0.38)	-0.73	0.729	0.53

Δ = difference

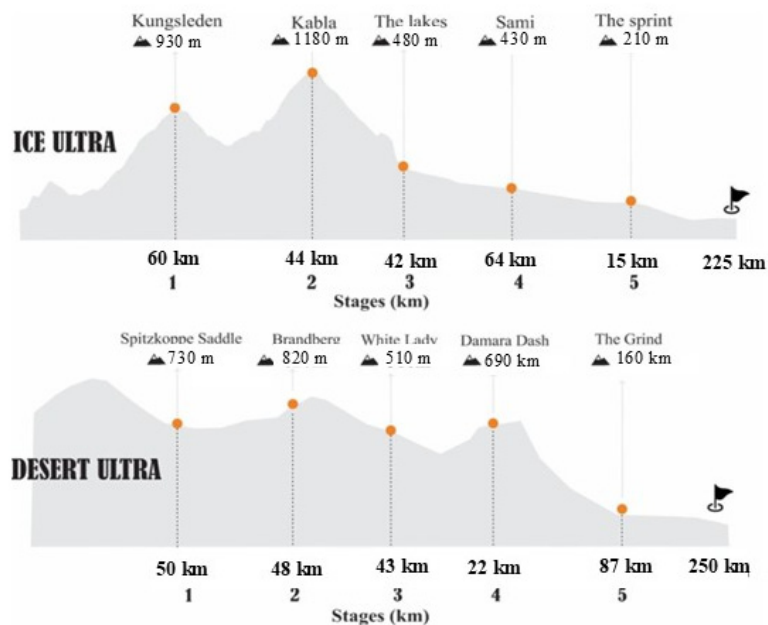


Figure 1. Stage distances and the altitude of Ice Ultra and Desert Ultra events.

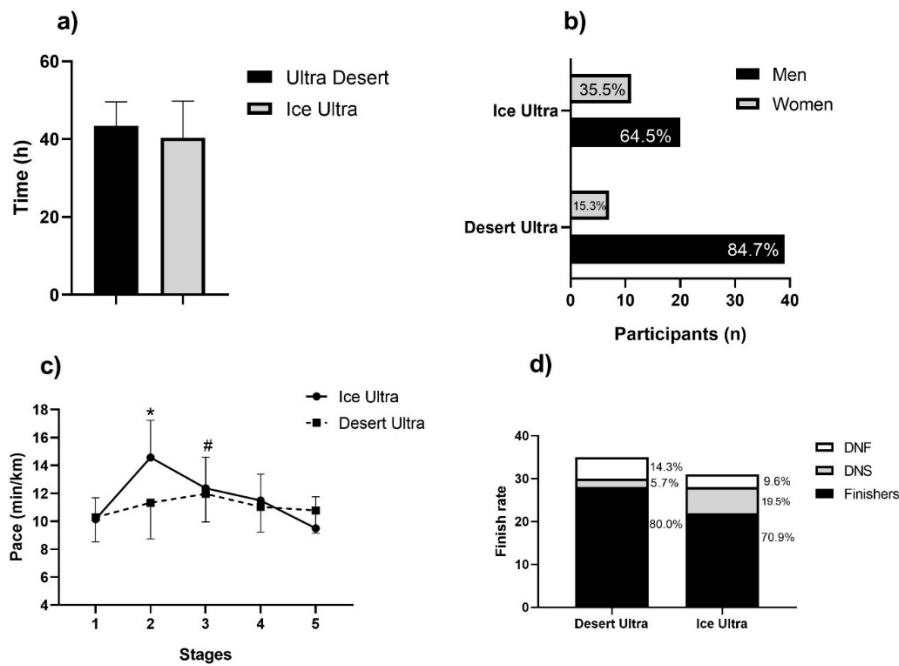


Figure 2. Comparison between events for main outcomes: a) total time of the five test stages; b) percentage of finishers; c) pace between particular running stages. * Ice Ultra: point 2 vs. point 1, point 3, point 4, point 5, $p < 0.001$; and Desert Ultra: point 1, point 2, point 3, point 4 and point 5; $p < 0.001$; # point vs. previous point; $p = 0.001$; d) rate of finishers (DNF: Did not finish, DNS: Did not start)

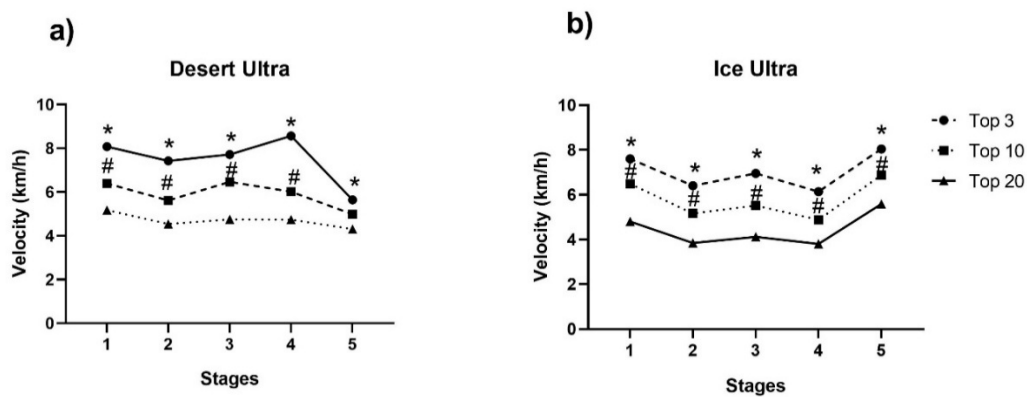


Figure 3. Analysis of velocity for each stage by event: a) velocity top 3, 10 and 20 Desert ultra. * Top 3: point 1, point 2, point 3 and point 5 vs. top 10 and 20 stages; $p < 0.01$; # Top 10: point 1, point 2, point 3 and point 5 vs. Top 20 stages; $p < 0.001$; b) velocity Top 3, 10 and 20 Ice Ultra. * Top 3: point 1, point 2, point 3 and point 5 vs. Top 10 and 20 stages; $p < 0.05$; # Top 10: point 1, point 2, point 3 and point 5 vs. Top 20 stages; $p < 0.001$

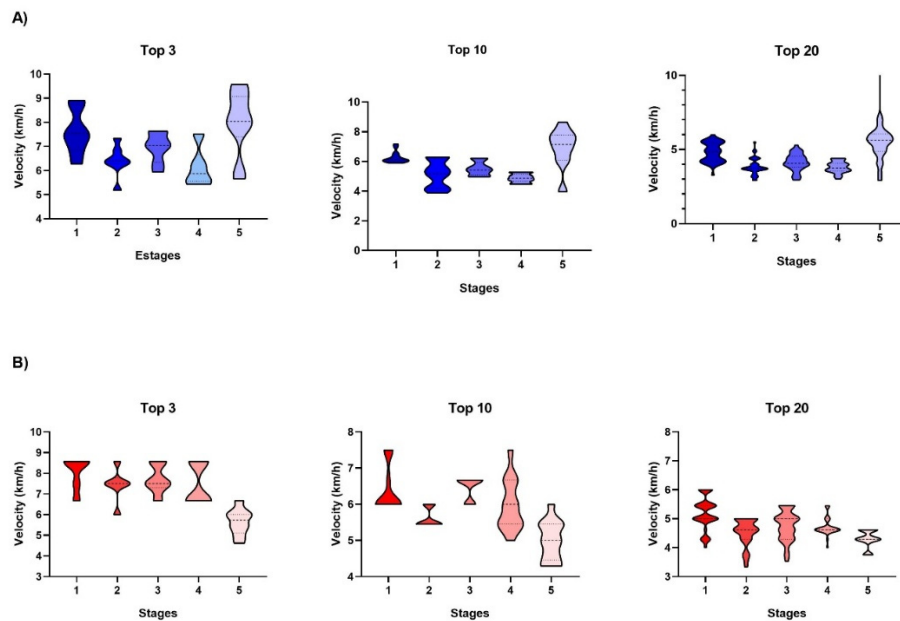


Figure 4. Comparison of velocity at each stage by group and event via violin plot. A) Ice Ultra event; B) Desert Ultra event.

Discussion

The present study aimed to investigate the pacing strategies of competitive ultramarathons for five days under extreme hot or cold weather conditions. We hypothesized that a decline in pacing would be observed throughout the stages. There was a parabolic running strategy between the subsequent days in the Ice Ultra (Top 3, Top 10, and Top 20) and the Top 20 Desert Ultra runners. A negative pacing profile from stage 2 in the Ice Ultra groups was also observed. Among the Top 20 participants, maintenance of the velocity pattern throughout the competition days was evident. The largest velocity amplitudes were observed among participants in the lower volume stages. Higher densities showed high heterogeneity among runners regardless of desert or ice running.

At both types of the competitions, specific care to maintain the body's thermal balance is required (Parise and Hoffman, 2011). Notably, these competitions present opposite temperature

challenges, with different routes and terrain in extreme environments. At the Ice Ultra event, in theory, runners may expect lesser impairment in physical performance—since this race is performed at low temperatures, it presents favorable humidity conditions and lesser dehydration compared with high temperatures (Bouscaren et al., 2019). In contrast, under extremely hot environmental conditions, greater impairment is expected (Guy et al., 2015) —prolonged dynamic exercise in the heat induces thermal stress, possibly negatively influencing pacing and increasing muscle fatigue (Bouscaren et al., 2019). Moreover, high skin and body temperatures, even in modest increments, are related to a decrease in aerobic performance and reduced work, impairing pacing strategies (Ely et al., 2010).

The average running time of the Ice Ultra runners demonstrated good performance on ice and snow terrain compared with the desert (Δ of 2

min/km). This result was interesting because some factors make it difficult to run in temperatures close to -40°C , such as heavier clothing, thermal equipment, and especially boots used in the snow, which are up to 1,500 g heavier than traditional running shoes. Furthermore, depending on the slope of the terrain and the need to save energy, the stride rate can be reduced (Ebben et al., 2008); therefore, the higher altitude in the Ice Ultra race (maximum slope of 1180 m in stage 2) could significantly interfere with the stride rate.

Participation in the Ice Ultra and Desert Ultra competitions predominantly consisted of male runners, which was previously observed in long-distance competitions up to 100 km and over 360 km (de Souza et al., 2022). However, an increase in female participation in other events, including marathons, in which for years males had predominated, was recently identified (Knechtle et al., 2020). At other ultramarathons, the annual participation of women has also exhibited growth (de Souza et al., 2022). Female runners represented an average of 16.4% of the total number of ultramarathon participants, with most finishers being from Europe, mainly France, followed by the United States, Asia, Africa, Australia, and South American countries (Shoak et al., 2013).

Recent research has identified that the number of finishers in ultramarathons held in multiple stages increased exponentially from 2010 to 2020 (de Souza et al., 2022). However, in the present study, there were fewer participants in the Ice Ultra and Desert Ultra competitions (<50 runners per competition), which might be expected compared with non-extreme events (Scheer, 2019). Complex logistics, accommodation, food, high registration costs, and access to the event venue can explain the low number of participants in both Ice and Desert events.

In the Ice Ultra event, 10.6% of runners “did not start” and in the Desert Ultra event, 21.8% started the competition but gave up in the following days, which may be related to emergences of disorders induced by high temperature exposure (Bergeron, 2014), as running in hot weather is associated with heatstroke, delusions, and seizures, which can lead to a state of coma in more serious situations (Leon and Bouchama, 2015).

Over the five days, the Ice Ultra runners gradually improved their pace after stage 2,

possibly due to the course's slope. This trend was not observed in the Desert Ultra event, which showed higher pacing maintenance among the competitors. Furthermore, conservative pacing was identified in the Top 20 runners in both competitions, which may be related to the goal of completing the course and not competing for winning. Nevertheless, the Top 3 runners showed higher variability in velocity. This rhythm variation potentially allowed athletes to achieve a prominent position in the final ranking, as these athletes' experience possibly allowed better management of velocity at different altitudes without compromising energy expenditure (Damsted et al., 2019; Martínez-Navarro et al., 2021).

The process of varying intensity involves a certain degree of risk management whereby the athlete induces higher homeostatic disturbances (Périard et al., 2021). We may infer that the Top 3 runners learnt to calculate potential risks, highlighting the importance of runner experience in avoiding errors in pacing strategy, which is a common occurrence in less experienced runners. An error in the pacing strategy can result in a radical drop in velocity at critical moments. These errors can occur because less experienced runners may not be accustomed to physiological stress and fatigue, such as muscle glycogen depletion in prolonged running (Jeukendrup, 2011). Thus, an ideal pacing strategy for multiple days should allow the athlete to spend energy cautiously, managing homeostatic disturbances (Périard et al., 2021).

Based on the course analysis, terrain, and more specifically relief, may have been an important factor in the strategic running rhythm. Different types of relief and terrain make it difficult to compare the two considered events. In the Ice Ultra race, the runners' velocity reduction was observed over the initial stages, which consisted of steeper terrain. For the last stages, a favorable slope facilitated a gradual increase in velocity.

The Ice Ultra runners exhibited a parabolic running strategy throughout the competition days. In the Desert Ultra event, a substantial reduction in velocity in stage 3 was observed, even in the absence of an incline. A possible explanation could be the implementation of a moderate pacing strategy, as stage 3 is the halfway point of the race, during which it is necessary to manage previous

stages of fatigue. Daily temperature fluctuation data from the analyzed events were not available, and they could potentially contribute to some differences.

Throughout the stages, a similar trend in the change in velocity was noted in both competitions and among different groups. The effect size results indicated a more substantial effect, especially when there were significant variations in the altitude and distance. Furthermore, those observations can be attributed to environmental challenges such as the course, weather conditions (wind and temperature) (Haney and Mercer, 2011), as well as individual factors including training background, tactical planning, nutrition, fatigue, and the mood (Bianchi et al., 2022; Costa et al., 2019). Investigating these relationships could provide valuable insights into optimizing performance and understanding how athletes adapt to different running conditions and challenges.

One of the main strengths of violin plots is their potential to reveal peaks, valleys, and bumps in the form of distributions (Hintze and Nelson, 1998). These features can be useful for range identification and comparing distributions. By carefully examining the speed graphs (Figure 3) and the violin plots, we can obtain more quality information about speed at different levels of participants. Figure 4 shows violin plots of the speed trajectories in the 5 stages of running.

The greatest speed amplitudes could be clearly observed among participants (Top 3, Top 10, and Top 20) in the race stages that presented a lower race volume (15 km), as observed in stage 5 of the Ice Ultra race, or the highest race volume (87 km), as observed in stage 4 of the Desert Ultra race. Higher densities show a greater concentration of athletes at a given speed; moreover, most stages showed high heterogeneity among runners. Naturally, higher speeds were also expected for most experienced participants with a higher performance level (Top 3).

A recent study (De Waal et al., 2025) that investigated the relationship between uphill, downhill, and level running with overall performance, as well as compared pacing strategies among finishers of a 100-km ultra-trail marathon, found that uphill running exhibited the strongest association with overall performance when compared to level and downhill segments.

This finding supports the results of our study and is further substantiated by evidence showing that Top 10 runners experience less decline in their initial running speed compared to non-Top 10 runners, despite the generally high variability in pacing and a prevalent positive pacing strategy in ultra-trail running.

Likewise, another study reinforced the variability of rhythm resulting not only from altitude but also from gender (Markovic et al., 2025). That study, which evaluated 3837 runners (3068 men (80%) and 769 women (20%)) competing at the Western States 100-Mile Endurance Run examined pacing strategies of successful finishers in the ultra-trail race considering gender, age, and the performance level. Pacing showed great variability between subsequent checkpoints in both men and women, which was mainly influenced by elevation. Moreover, male runners started faster and slowed down more than female runners.

The present study has some limitations that need to be acknowledged. It is important to highlight the low number of participants in the Desert Ultra and Ice Ultra events. However, unlike short-distance (5 km, 10 km) and long-distance running events (half marathon), the Desert Ultra and Ice Ultra competitions are not considered leisure activities. Although we considered the influence of changes in elevation, the aspects of nutrition and environmental conditions could not be taken into account. The Desert Ultra and Ice Ultra events attract a very specific group of runners willing to undergo additional challenges under extreme conditions. Furthermore, the use of mixed models and integration of demographic variables is recommended for future studies, for example, the detailed breakdown of participants' age, training history, nationality, or altitude acclimatization.

Furthermore, although the current study compared similar conditions such as the total distance and the number of stages, it does include factors that may compromise some comparisons, such as those related to the altitude and distances between stages. In addition, future studies should also consider analyzing the moderating effects of sex on the current findings to avoid generalization of findings for both males and females.

Practical Implications

Our findings implicate that both relief (i.e., topography) and weather play an important role in the strategic pacing of ultramarathon runners. Athletes preparing for ultramarathon competitions that may exhibit extremely hot or cold weather conditions and changes in the altitude, must train to start with a slower pace and maintain consistency in their pace throughout the race. In addition, athletes should also be aware that the best strategy to reach the finish line is to be cautious and prioritize own safety.

Conclusions

Ice Ultra runners displayed a parabolic running strategy. In the Desert Ultra race, a substantial reduction in speed was observed even when there was no slope and even halfway through the completion of the pacing strategy stages. Managing fatigue from previous stages and temperature fluctuations are relevant factors that need to be better explored.

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