International Journal of Sports Physiology and Performance, 2011, 6, 243-251

Influence of Temperature and Performance Level on Pacing a 161 km Trail Ultramarathon

Carol A. Parise and Martin D. Hoffman

Background: Even pacing has been recommended for optimal performances in running distances up to 100 km. Trail ultramarathons traverse varied terrain, which does not allow for even pacing. ***Purpose:*** This study examined differences in how runners of various abilities paced their efforts in the Western States Endurance Run (WSER), a 161 km trail ultramarathon in North America, under hot vs cooler temperatures. ***Method:*** Temperatures in 2006 (hot) and 2007 (cooler) ranged from 7–38°C and 2–30°C, respectively. Arrival times at 13 checkpoints were recorded for 50 runners who finished the race in both years. After stratification into three groups based on finish time in 2007 (<22, 22–24, 24–30 h), paired *t* tests were used to compare the difference in pace across checkpoints between the years within each group. The χ^2 test was used to compare differences between the groups on the number of segments run slower in the hot vs cooler years. ***Results:*** For all groups, mean pace across the entire 161 km race was slower in 2006 than in 2007 (9:23 ± 1:13 min/km vs 8:42 ± 1:15 min/km, $P < .001$) and the pace was slower from the start of the race when temperatures were still relatively cool. Overall, the <22 h cohort ran slower in 2006 than 2007 over 12 of the 14 segments examined, the 22–24 h cohort was slower across 10 of the segments, and the >24 h cohort was slower across only 6 of the segments $\chi^2_2 = 6.00$, $P = .050$). Comparable pacing between the 2 y corresponded with onset of nighttime and cooling temperatures. ***Conclusions:*** Extreme heat impairs all runners' ability to perform in 161 km ultramarathons, but faster runners are at a greater disadvantage compared with slower competitors because they complete a greater proportion of the race in the hotter conditions.

Keywords: trail running, extreme heat, athletic performance, physical endurance, pacing

Even pacing is generally recommended for optimal race performances in running distances up to 100 km.[1–3] The fastest competitors tend to run the first segments of a race at a similar or slightly faster speed than the last portion of a race.[4–6]

Carol A. Parise is with the Sutter Institute for Medical Research, Sacramento, CA. Martin D. Hoffman is with the Department of Physical Medicine and Rehabilitation, VA Northern California Health Care System, and the University of California Davis Medical Center, Sacramento CA.

Increased ambient temperature has a well-documented negative impact on running performance and pacing. In the marathon, higher environmental temperatures slow competitors of all abilities, but have a greater adverse effect on finish times among slower runners while interfering more with even pacing among faster runners.[1–3] Previous explorations of how temperature influences pacing have been conducted in the confines of a laboratory or associated with flat, road race courses.[2,4,5] No studies have examined these factors for running distances beyond 100 km and under the typical conditions of such events.

Trail ultramarathon races present a unique challenge to the examination of factors associated with pacing since the courses often traverse varied terrain, which does not allow for even pacing. Because these races are longer, they take place over an extended time period compared with marathons so temperatures may widely fluctuate from the start to the finish of the race. While the terrain of many courses does not allow for even pacing as in flat road races, times between checkpoints can be computed allowing for analysis of conditions that may influence pacing over various segments of a trail course.

The present study utilizes data from the Western States Endurance Run (WSER), the first-ever trail 161 km ultramarathon. At the beginning of 2009, around 20% of the over 32,000 161 km ultramarathon finishes in North America were at the WSER, and approximately 35% of the 9815 individuals who were known to have finished a 161 km ultramarathon in North America had completed this event.[7,8] The WSER is a point-to-point trail race through the Sierra Nevada Mountains in Northern California. From the start at the base of the mountains in Squaw Valley, the current course ascends nearly 780 m in the first 7 km. The run then follows trails used by the gold and silver miners of the 1850s, climbing a total of 5500 m and descending 7000 m before reaching the finish in Auburn 100.2 miles (161.3 km) from the start. The route largely traverses rough and inaccessible land reaching a maximal altitude of 2667 m. The challenges resulting simply from the distance, terrain, and altitude are sometimes compounded by snow cover in the early sections of the course and high temperatures later in the run. As such, this run is one of the toughest organized running events in the United States. Runners are allowed 30 h to complete the race. Each entry is required to have completed at least an 80 km race during the prior year.

A previous study of WSER runners found that elevated ambient temperatures were associated with slower finishing times and an increased probability of dropping out for both men and women.[9] However, the effect of higher temperatures on pacing over various segments of this course has not been studied. Thus, the purpose of this study was to examine differences in how runners of various abilities pace their efforts in the 161 km WSER under hot vs cooler temperatures.

Methods

Two consecutive years when the race took place under very different environmental temperature conditions were identified. Temperatures during the event in 2006 were especially hot, whereas the conditions in 2007 were relatively mild for this event. The course was identical both years except that in the hot year, there was intermittent snow cover on the first 12 km of the trail, which had minimal impact since the snow was hard packed. On inspection of the race results, the finish rates were markedly different between the 2 y and dropouts occurred earlier in the race in 2006 than in any other year (Figure 1). Considering the 23 races held between 1986 and 2009, only two had a lower finish rate than the 52.6% in 2006, and only three had a higher finish rate than the 69.8% in 2007. As such, the 2006 and 2007 offered two consecutive years appropriate for comparison.

Due to the remoteness of the course, exact temperature data were not available along the trail, but hourly historical data were available for two nearby locations. Temperatures were linked to the race for the city near the race start (Truckee, California) up to the 48 km checkpoint and from the finish (Auburn, California) for the remainder of the course. Use of the temperatures from these sites invariably underestimated the actual temperatures through some parts of the course where radiation contributed to the thermal load.

During the race in 2006 (hot year), temperature ranged from 7.2°C to 38.0°C, humidity ranged from 46% to 56%, and wind speed was 2 to 10 km/h. In contrast, the temperature in 2007 (cooler year) was 2.2°C to 30.6°C, humidity was 38% to 43%, and there was no measurable wind.

Official race results were examined to identify the runners who had finished the race both years. The posted results also provided arrival times at 13 checkpoints and the finish for each runner. Time differences and mean pace (min/km) between these checkpoints were computed. Age, sex, and body mass index (BMI) determined in 2007 were obtained. Measurements for determination of BMI were made at check-in the day before the 2007 race as detailed in a previous publication.[10] The number of previous WSER finishes and other 161 km experience was determined from our historical data.[7,8] Runners were then stratified into three groups (<22, 22–24, and >24 h) based on their finish time in the 2007 (cooler year) event.

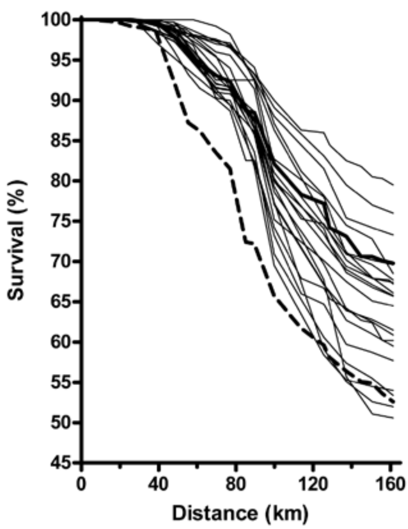

Figure 1 — Proportion of starters remaining in the race at each checkpoint on the course for each of the 23 events held between 1986 and 2009, inclusive. The thicker dashed curve is for 2006 and the thicker solid curve is for 2007.

Pearson's correlations were used to assess the associations between BMI and finish times in 2006 and 2007. One way ANOVA and Tukey post hoc follow-up tests were used to assess differences in age, BMI, and mean number of previous WSER finishes among runner groups.

The paired *t* test was used to compare differences in pace between the hot and cooler years over the entire course and across 14 segments within each of the three cohorts of runners of similar finish times in 2007. Because of the variation in terrain and elevation changes within different course segments, we were not interested in comparing differences in running speed between segments. The χ^2 test of independence was then used to compare differences between the groups on the number of course segments run slower in the hot vs cooler years.

The study was approved by our institutional review board with the requirement for informed consent waived since all data analyzed were publicly available.

Results

Two hundred ten runners finished the race in 2006 and 270 finished the 2007 event. There were 8 women and 42 men who finished the race both years who comprised the study cohort. Table 1 shows the mean age, BMI, number of WSER finishes before 2006, and overall pace for runners in each of the three 2007 finishing strata. Tukey post hoc tests indicated that runners who finished the race in 2007 in <22 h (P = .000) and those finishing in 22–24 h (P = .005) were younger than runners who finished the 2007 race in >24 h. There were also no differences between the three groups with respect to BMI (P > .067) or number of prior finishes (P > .158). For all runners, BMI was correlated with finish time in 2006 (r = .34, P = .015) but not in 2007 (r = .256, P = .073).

Only 12 runners in the study group had not previously finished the WSER and only 5 had not previously finished at least one 161 km run. For all groups, overall

Table 1 Demographics and overall pace for finishers of the 2006 and 2007 WSER stratified by 2007 finish time and with the age and BMI data from 2007

	<22 h	22–24 h	>24 h
	(n = 16, 4 women)	(n = 18, 3 women)	(n = 16, 1 woman)
Age (y)	38.5 ± 6.6*	43.8 ± 8.1*	52.8 ± 8.7
BMI (kg/m^2)	21.4 ± 1.9	21.4 ± 1.7	22.9 ± 2.0
WSER finishes before 2006	2.3 ± 2.3	3.4 ± 3.7	5.3 ± 6.2
Pace (min/km)			
2006	8:09 ± 0:56	9:22 ± 0:43	10:37 ± 0:21
2007	7:20 ± 0:37	8:35 ± 0:11	10:10 ± 0:35
Difference	0:49 ± 0:44†	0:47 ± 0:42†	0:27 ± 0:29†

Note. Data are reported as mean ± SD. *P < .005 compared with >24 h finishers. †P < .003 for within group comparison between years.

average pace for the full 161 km was slower in 2006 than in 2007 by 27 to 49 sec per km (Table 1). Considering all 50 runners, mean finish times were 25:13:18 (pace 9:23 ± 1:13 min/km) in 2006 compared with 23:23:14 (pace 8:42 ± 1:15 min/km) in 2007 ($t_{49} = -7.31$; $P = .000$). Average pace and finish times were well correlated ($r = .86$, $P = .000$) between the 2 y (Figure 2). Figure 3 demonstrates how mean pace across each segment of the course compared between years for each group of runners. Course elevation profile is also displayed to provide some insight into the variations in pace. With the exception of one segment, paces across each segment were slower in 2006 than in 2007 up to 90 km for the >24 h cohort. Pace was slower in 2006 than in 2007 for the 22–24 h cohort up to 126 km, and for the <22 h cohort, up to 145 km. Overall, the <22 h cohort ran slower in 2006 than 2007 over 12 of the 14 segments examined, the 22–24 h cohort was slower across 10 of the segments, and the >24 h cohort was slower across only 6 of the segments ($\chi^2_2 = 6.00$, $P = .050$).

The temperature range experienced each year by the three cohorts is displayed in Figure 4. In 2006, all runners were exposed to temperatures above 35°C by the midpoint of the course, and temperatures remained above 30°C until it was dark. As a result, those in the <22 h cohort completed most of the course at temperatures above 30°C whereas all of those in the 22–24 h cohort were running in temperatures below 30°C by around 120 km. For the >24 h cohort temperatures were below 30°C by around 110 km. This contrasts with the conditions in 2007 when temperatures were above 30°C for only a brief period.

Discussion

This study provides insight into how runners pace their efforts over a 161 km trail ultramarathon race, and how the pacing is affected by ambient temperature. The pace varied considerably relative to the terrain, but runners slowed over the course of the run and were adversely affected by hot conditions, although these effects were less evident for the slower runners compared with faster runners. However, these

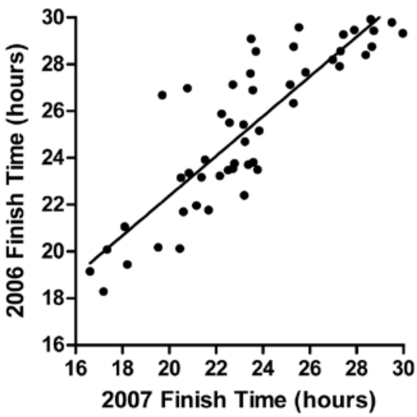

Figure 2 — Relationship between finish times for the 2 y.

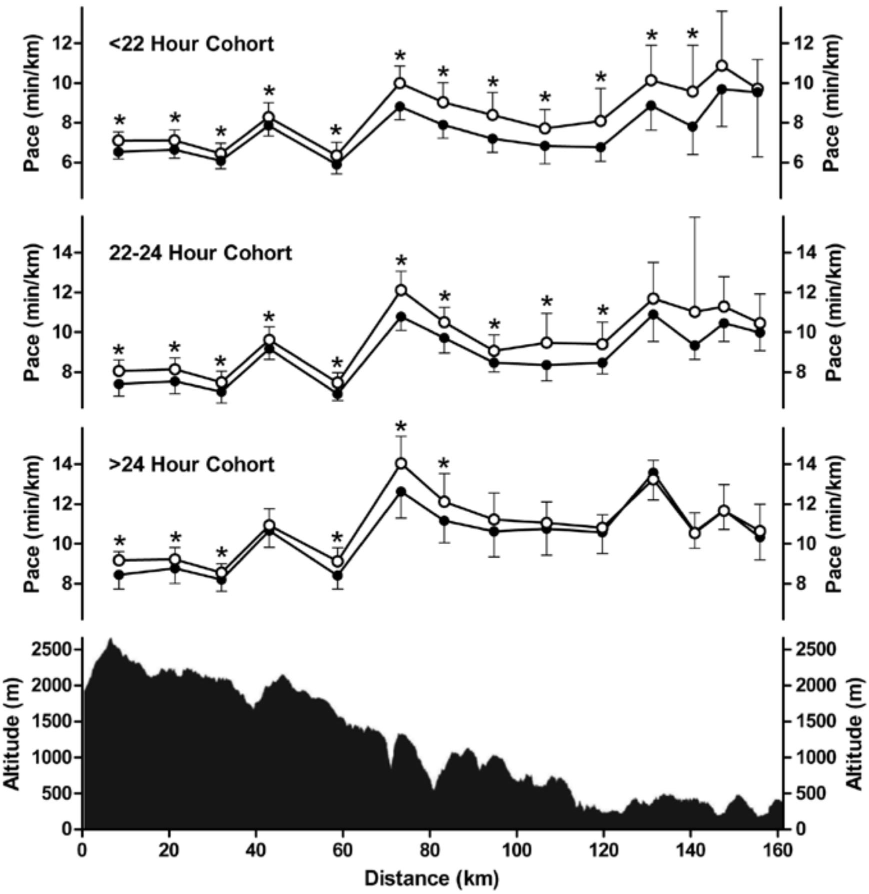

Figure 3 — Mean pace across each segment of the course for 2006 (open circles) and 2007 (closed circles) for each cohort. Brackets represent 1 SD and are shown in only one direction for clarity. *Indicates a statistically significant difference ($P < .050$) between years. The course elevation profile is included at the bottom of the figure.

results indicated that even in the early stages of the race where temperatures were still relatively cool, runners of all performance levels were 35 to 45 s/km slower in the hot year compared with the cooler year. While the intermittent snow pack in the early stages of the run during the hot year might have partially explained the slower pace, this effect cannot be responsible for any difference in pace beyond the first segment of the course. As such, it seems that runners adjusted pace in recognition of impending temperature elevations.

Tucker[6] postulated that in self-paced exercise, athletes set their initial exercise intensity using physiologic input such as skin temperature, expected exercise duration, and previous experience. The slower pace early in the race during the hot year may be explained with this model. The early stages of WSER are on trails above 2000 meters with very little shade, which exposes runners to the direct sun

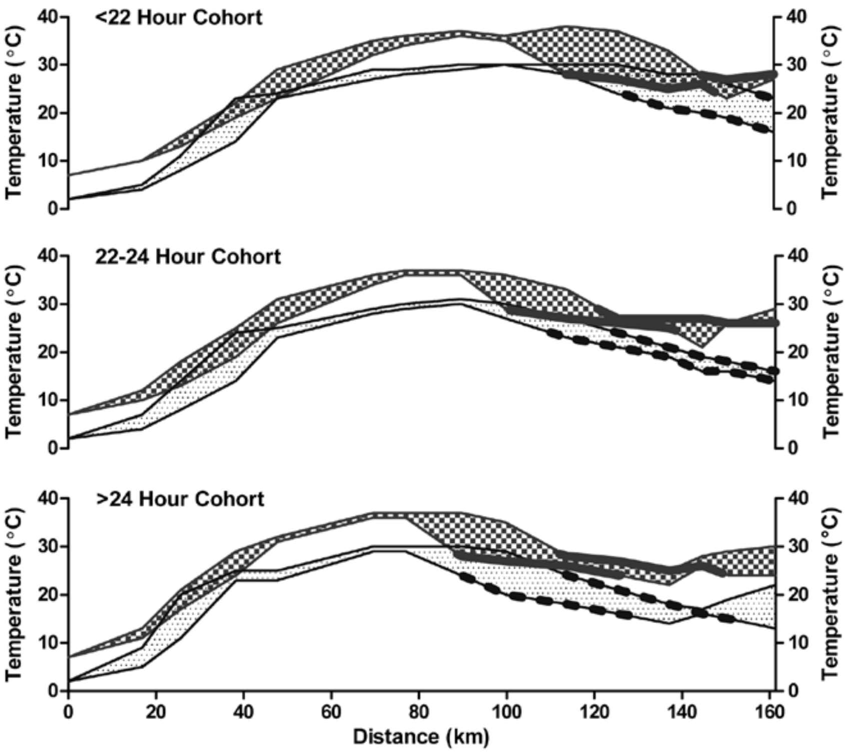

Figure 4 — Temperature range experienced in 2006 (checkered zones) and 2007 (stippled zones) by the three cohorts. Thick solid (2006) and dotted (2007) curves define the sections traversed in darkness by the fastest (upper curve) and slowest (lower curve) runners of each cohort.

and increases the skin temperature. All runners also had previous ultramarathon running experience and were well aware of the duration of the current event. This feedback may have been responsible for runners setting their initial intensity at a level they thought could be sustained for the duration of the event.

Pacing differences between faster and slower runners have been previously noted at the marathon distance.[1,2] A study of marathon finishers on a flat course indicated that the fastest runners maintain an even pace under cool conditions but slow down in the second half of the race under hot conditions.[2] In contrast, the slowest runners slow their pace throughout the 42 km race regardless of the temperature, and their finish times are more affected by the heat than the fastest runners.[1,2]

As opposed to previous findings related to the marathon, our results demonstrate that the hot conditions had less of an adverse effect on finish time of the slower runners than the faster runners. However, in the case of the present study, the finding can be partially explained by a combination of the distance that runners traversed during the extreme temperatures and the extent of running in the dark that was required.

Figure 3 shows that the effect of the hot conditions on slowing pace was remarkably similar among cohorts until approximately 100 km. It was at this point when nighttime and cooler temperatures arrived for the slower runners. In contrast, the fastest runners covered a greater distance before sunset while still in the extreme heat of the day. In fact, during the hot year, the <22 h cohort covered as much as 140 km before temperatures dropped below 30°C, while the 22–24 and >24 h cohorts had completed only as much as 120 km and 110 km before temperatures dropped below 30°C, respectively. After sunset, the slowed pace due to darkness and the inherent difficulties in seeing the trail as well as during daylight probably also limited the differential in pace resulting from the higher temperatures.

Examination of Figure 3 also demonstrates that pace abruptly slowed among all three cohorts at around 70 km and that the effect of the hot conditions on slowing pace appeared to be greater at this point. This slowing in pace coincided with a nearly 20 km section that included two major climbs. Temperatures were also roughly at their highest through this section for all cohorts. Since the hottest and most difficult sections of the course occurred simultaneous, it is not possible to determine if characteristics of the terrain altered the effect of heat on pacing.

The present study found that the relationship of BMI with finish time was statistically significant for the hot conditions but did not reach significance for the cooler conditions. Although, when considering all finishers in the cooler race of 2007, we demonstrated significant relationships between BMI and finish time for both men and women,[10] the lack of significance for this relationship in the present study was due to the small subset of runners that was considered. Yet, the stronger relationship of BMI with finish time under hot conditions suggests that body characteristics may be a more important performance factor under hot conditions than cooler conditions. This would be consistent with an earlier finding that smaller body mass and BMI were associated with faster 8 km running times under hot conditions among runners with similar performances under cool conditions.[11]

The present study is unique in that it includes the same experienced ultramarathon runners over the same course in hot vs cooler conditions. This repeated measures design minimizes between person variability so that the difference in pace of runners between the two years is more likely due to actual differences in environmental conditions rather than a product of sampling. The strong correlation in finish times between years (Figure 2) without major outliers also supports the consistency of effort each year for the study population. This design's disadvantage is that it introduces selection bias since in order to be included in the study cohort, a runner had to complete the race both years. We do not know if runners who eventually dropped out of the race in 2006 did so because they were too slow to meet the cutoff time or if they did not adjust their pace to the conditions and were unable to continue at some point. In addition, there were only eight females that completed both years, and this did not allow us to address potential gender differences. Despite this weakness, 50 runners represents a solid sample given that the number of finishers each year is typically less than 300.

The chief limitation of this study is that we did not have exact temperature data available at each checkpoint. It was necessary to rely on temperatures from two locations near the course from which historical data were available. These values did not accurately represent the actual course temperature for which maximal temperatures were recognized to be higher. However, they provided an adequate approximation and pattern of the actual course temperatures.

Practical Applications

- Ultramarathon runners should anticipate slower times in extreme heat but faster competitive runners should be cognizant that the conditions will impact their performance the most.
- Although extreme heat of the day may abate during the night and morning, trail running pace through the night seems to be as limited by the inherent difficulties of running in the darkness as by high temperatures.

Conclusion

Completion of a 161 km trail run is an arduous endeavor that requires both physical and psychological preparation. Runners compensate for impending high temperatures by slowing their pace during the early stages of the race. Extreme temperatures impair all runners' ability to perform but faster runners are affected more than slower competitors.

Acknowledgments

This material is the result of work supported with resources and the use of facilities at the VA Northern California Health Care System and Sutter Institute for Medical Research.

References

1. Ely MR, Cheuvront SN, Roberts WO, Montain SJ. Impact of weather on marathon-running performance. *Med Sci Sports Exerc*. 2007;39(3):487–493.
2. Ely MR, Martin DE, Cheuvront SN, Montain SJ. Effect of ambient temperature on marathon pacing is dependent on runner ability. *Med Sci Sports Exerc*. 2008;40(9):1675–1680.
3. Trapasso LM, Cooper JD. Record performances at the Boston Marathon: biometeorological factors. *Int J Biometeorol*. 1989;33(4):233–237.
4. Gosztyla AE, Edwards DG, Quinn TJ, Kenefick RW. The impact of different pacing strategies on five-kilometer running time trial performance. *J Strength Cond Res*. 2006;20(4):882–886.
5. Lambert MI, Dugas JP, Kirkman MC, Mokone GG, Waldeck MR. Changes in running speeds in a 100 KM ultra-marathon race. *J Sports Sci Med*. 2004;3(3):167–173.
6. Tucker R. The anticipatory regulation of performance: the physiological basis for pacing strategies and the development of a perception-based model for exercise performance. *Br J Sports Med*. 2009;43(6):392–400.
7. Hoffman MD, Ong JC, Wang G. Historical analysis of participation in 161 km ultramarathons in North America. *Int J Hist Sport*. 2010;27(11):1877–1891.
8. Hoffman MD, Wegelin JA. The Western States 100-Mile Endurance Run: participation and performance trends. *Med Sci Sports Exerc*. 2009;41:2191–2198.
9. Wegelin JA, Hoffman MD. Variables associated with odds of finishing and finish time in a 161-km ultramarathon. *Eur J Appl Physiol*. 2011;111:145–153.
10. Hoffman MD. Anthropometric characteristics of ultramarathoners. *Int J Sports Med*. 2008;29(10):808–811.
11. Marino FE, Lambert MI, Noakes TD. Superior performance of African runners in warm humid but not in cool environmental conditions. *J Appl Physiol*. 2004;96(1):124–130.