RESEARCH NOTE

Selected Human Physiological Responses During Extreme Heat: The Badwater Ultramarathon

Jacqueline S. Brown and Declan A. Connolly

Department of Physical Education, The University of Vermont, Burlington, Vermont

Abstract

Brown, JS and Connolly, DA. Selected human physiological responses during extreme heat: The Badwater Ultramarathon. *J Strength Cond Res* 29(6): 1729–1736, 2015—The purpose of this article was to examine various physiological responses during an ultramarathon held in extreme heat. Our investigation was conducted at The Badwater Ultramarathon, a nonstop 217-km run across Death Valley, CA, USA. This study recruited 4 male athletes, average age of 43 (±*SD*) (±7.35), (range) 39–54 years. All 4 subjects successfully completed the race with a mean finish time of 36:20:23 hours (±*SD*) (±3:08:38) (range) 34:05:25–40:51:46 hours, and a mean running speed of 6.03 $km \cdot h^{-1}$ (±*SD*) (±0.05), (range) 5.3–6.4 $km \cdot h^{-1}$. The anthropometric variables measured were (mean, ±*SD*) mass 79.33 kg (±6.43), height 1.80 m (±0.09), body surface area 1.93 m^2 (±0.16), body mass index 24.38 $kg \cdot m^{-2}$ (±1.25), fat mass 13.88% (±2.29), and body water 62.08% (±1.56). Selected physiological variables measured were core body temperature, skin temperature, heart rate, breathing rate, and blood pressure. Rate of perceived intensity, rate of thermal sensation, and environmental factors were also monitored. Our study found (mean and ±*SD*) core body temperature 37.49° C (±0.88); skin temperature 31.13° C (±3.06); heart rate 106.79 $b \cdot min^{-1}$ (±5.11); breathing rate 36.55 $b \cdot min^{-1}$ (±0.60); blood pressure 128/86 mm Hg (±9.24/4.62); rate of perceived intensity 5.49 (±1.26); rate of thermal sensation 4.69 (±0.37); daytime high temperature of 46.6° C, and a mean temperature of 28.35° C. Our fastest finisher demonstrated a lower overall core body temperature (36.91° C) when compared with the group mean (37.49° C). In contrast to previous findings, our data show that the fastest finisher demonstrates a lower overall core body temperature. We conclude that it may be possible that a time threshold exists whereby success in longer duration events requires an ability to maintain a lower core body temperature vs. tolerating a higher core body temperature.

Key Words core body temperature, skin temperature, ultraendurance, rate of perceived intensity, rate of thermal sensation

Introduction

Ultraendurance events are becoming more and more popular every year, challenging our perception of the limits of human endurance. In the United States, the number of ultrarunning events held over the last 4 years has grown from 89 to 446, and gaining entry into some of the most competitive events now requires being selected through a lottery system (13). As this participation grows, so does the risk for heat-related illnesses, especially with athletes competing in extreme heat. A reliable method for monitoring an athlete for early signs of heat disorders is measuring body core temperature (T°C) (7,8,19). The American College of Sports Medicine and the National Athletic Trainer's Association express in their position statements on "Exertional Heat Illnesses" that, as the body T°C rises to 40° C, the ability to be able to perform deteriorates accordingly (3,5). These position papers also state that once the body T°C has climbed above 40° C, the athlete is considered to have exertional heat stroke or exertional hyperthermia (3,5). Both papers also convey that if an athlete continues to exercise at a body T°C higher than this critical body T°C, more serious medical conditions such as heat stroke or death, may occur (3,5). Recent literature reveals that the validity of the 40° C critical point is now being challenged and that additional research is needed to understand the limits of human performance (11,15).

Initial studies assessing athletes were often performed in the laboratory and were based on the recommendations established by the classical desert research of the 1940s (22). As a result, guidelines were developed to identify and prevent heat-related illnesses that would negatively affect an athlete's ability to perform (4,16,22). Armstrong et al. (4) state that there is a large body of literature that indicates a loss in >2% body mass due to dehydration, will increase heat storage, and decrease time to exhaustion. In addition to

Address correspondence to Jacqueline S. Brown, jackie@jgbrowninc.com.

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Table 1. Characteristics of the subjects.*†

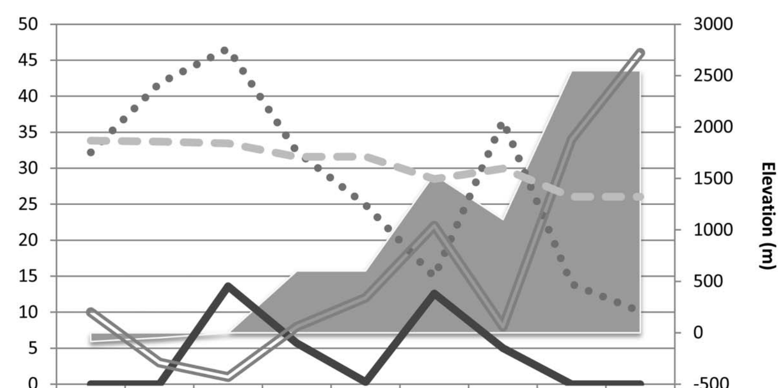
	Subject 1	Subject 2	Subject 3	Subject 4	Group mean ± *SD*	Range
Age (y)	54	39	39	40	43 ± 7.35	39–54
Weight (kg)	79.0	85.7	82.0	70.6	79.33 ± 6.43	70.6–85.7
Height (m)	1.80	1.82	1.90	1.69	1.80 ± 0.09	1.69–1.90
BSA (m^2)	1.77	2.05	2.08	1.81	1.93 ± 0.16	1.77–2.08
BMI ($kg \cdot m^{-2}$)	24.4	25.7	22.7	24.7	24.38 ± 1.25	22.7–25.7
%FM calipers	13.5	11.5	13.5	17.0	13.88 ± 2.29	11.5–17.0
%BW scale	61.1	63.5	63.3	60.4	62.08 ± 1.56	60.4–63.5

*BSA = body surface area; BMI = body mass index; %FM = percentage of fat mass; %BW = percentage of body water.
†The group mean ± *SD*, and range are reported.

the effects of dehydration and a body T°C above the critical point of 40° C, it has also generally been understood that several anthropometric parameters, such as body mass, height, body mass index, and fat mass, can influence athletic performance, and the degree of this impact depends on the duration of exercise (12). However, a recent study found that anthropometric measurements are not positively associated with race performance for athletes competing in a 100-km ultraendurance run (12).

Current literature suggests that the "classical desert studies" no longer address many concerns seen in modern athletes, especially those observed in the extreme endurance sports and exercise we see today (22). Yet, current research on ultraendurance athletes, particularly ultrarunners, is sparse and there is a need for further studies on this group of athletes, especially in field settings.

Original research in the study of body T°C in a marathon distance field setting was performed by Pugh et al. (20). These researchers measured the rectal temperatures in 77 runners competing at an ambient air temperature of 23° C and found their fastest finisher recorded the highest body T°C at 41.1° C (20). They also reported 3 of the first 4 finishers achieved a body T°C over 40.0° C (20). These researchers concluded that the findings imply that a tolerance of a high body T°C is a necessary condition of successful marathon running (20). Further research was performed by



	7/16 8:00 am	7/16 10:30 am	7/16 3:00 pm	7/16 9:12 pm	7/17 12:00 am	7/17 5:00 am	7/17 11:30 am	7/17 8:05 pm	7/18 3:18 am
Elevation (m)	-85.5	-50	0	600	600	1539	1100	2548	2548
Ambient Air (C°)	32.2	41.8	46.6	32.3	24.9	14.9	36.6	13.9	10.1
Wind Speed (km/h)	0	0.0	13.6	5.7	0.3	12.6	5	0	0
Relative Humidity (%)	10	3	1	8	12	22	8	34	46
Barometric Pressure (inHg)	33.84	33.7	33.44	31.57	31.61	28.5	29.96	26.03	26.03

Figure 1. The environmental conditions during the race.

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Wyndham and Strydom (24), in which they measured the body T°C of 2 groups of 20 runners, to measure the physiological responses of water deficits during two 20-mile running events. They found that the fastest runner (and winner) of both events achieved the highest body T°C, which was reported as 40.6 and 40.9° C, respectively (24). They concluded that this result corresponded to a drop in body weight and is in agreement with Pugh et al. findings (24). Two recent studies by Maron et al. (18) and Lee et al. (15) agree with the findings presented above. Based on the present literature, we hypothesized that the fastest finishers will demonstrate a higher body T°C vs. slower finishers.

The purpose of this descriptive field study is to examine various physiological responses of athletes performing in an ultramarathon held in extreme heat. The various parameters to be evaluated and examined include body T°C, skin temperature, heart rate, breathing rate, blood pressure, body mass, body mass index, body surface area, percentage of fat mass, percentage of body water, rate of perceived intensity, rate of thermal sensation, and environmental factors. These variables will be further compared with the athlete's ability to maintain a normal range in T°C and to successfully complete the run.

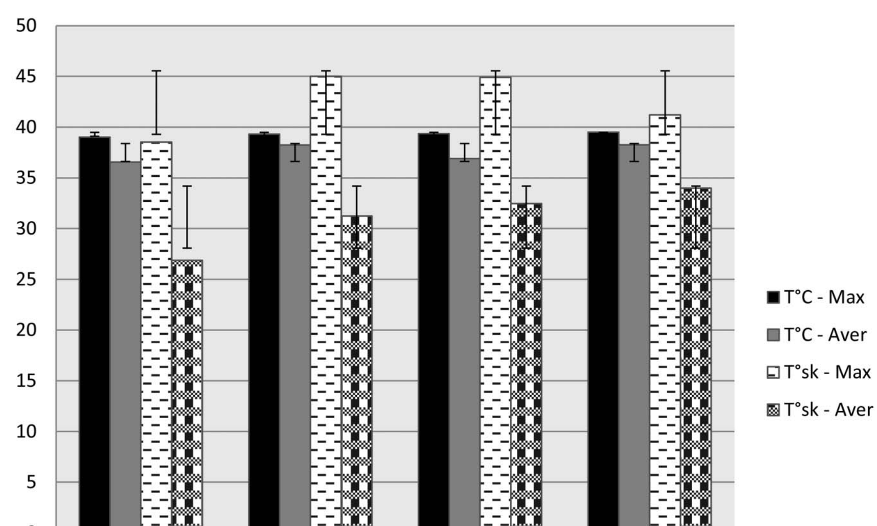
Methods

Experimental Approach to the Problem

This descriptive field study occurred at the Badwater Ultramarathon held in Death Valley (Mohave Desert), California on July 16–18, 2012. This race is a nonstop 217-km run on pavement, which starts at the lowest elevation point in the Western Hemisphere at 85.5 m below sea level, covers 3 mountain ranges, for a total cumulative vertical ascent of 3,962 m and a total cumulative descent of 1,433 m, and finishes at the trailhead of Mt. Whitney at 2,533 m (2). The cumulative vertical ascent begins after the 68 km-mark and continues to climb upward to the finish line, making the race progressively more challenging as the duration increases (2). Runners need to rely on their own support crew, as there are no aid stations along the course and approximately 90 participants are invited annually to participate (2). The 2012 race roster included 96 runners, of which 93% successfully finished the event under the 48-hour time limit. Ambient air temperatures during this race, which has been held during the month of July since 1977, can reach as high as 55° C (2). On day 1 of this year's race, the temperature was 32.2° C at the start line and reached a maximum of 46.6° C during the day and then dropped to 14.9° C in the evening. On day 2, the daytime high reached 36.6° C and fell to a low of 10.1° C at the finish line.

Subjects

Subjects were recruited before the race using a letter describing the study that was circulated by the race organizers to those runners listed on the race roster. The study was open to all runners on the roster. Runners



	Subject 1	Subject 2	Subject 3	Subject 4
T°C - Max	39.03	39.32	39.35	39.5
T°C - Aver	36.57	38.23	36.91	38.26
T°sk - Max	38.53	45	44.9	41.21
T°sk - Aver	26.86	31.23	32.45	33.98

Figure 2. The maximum and average body core temperature and skin temperature are reported for each subject. Data represent group mean ± *SD*.

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who were interested in the study were sent a copy of the informed consent, which was approved by The University of Vermont's Institutional Review Board for the use of Human Subjects, along with a questionnaire by e-mail. The questionnaire asked about the runner's general health, training history, heat training, and experience at this race.

Four male subjects volunteered to participate in this study. The investigators met with each subject the day before the race and once the appropriate written informed consent was signed, the questionnaire was collected and reviewed with each subject. Instructions were given to each athlete and their support crew on how to use the crew log sheet used to record data to be collected during the study. Each subject was informed that they would receive a summary of their individual results along with a summary of the study.

Procedures

Instructions were given to each subject and their support crew the day before the race, and prerace measurements were taken. After sitting quietly for at least 5 minutes, the subject's blood pressure was recorded, using an Aneroid Sphygmomanometer and Spraque-Style Stethoscope (Lumiscope Model #100-040, Columbia, SC, USA). Height (in centimeters) was measured and body mass (in kilograms) was recorded using a Tanita BF-680W Duo Scale (Body Fat Monitor/Scale, Arlington Heights, IL, USA). Body surface area was calculated using a height-weight formula as described by Du Bois and Du Bois (9). Body mass index was calculated using the Quetelet Index. The percentage of fat mass was then determined using the sum of 4 (Σ4) skinfold measurements with Lange Skinfold Calipers (Beta Technology, Santa Cruz, CA, USA) using a formula described by Durnin and Rahaman (10). The anthropometric characteristics are given in Table 1.

The subject was then instructed on the ingestion of the ingestible core temperature capsule (ICTC) using the manufacturer's recommendations. Instructions were also given on the placement of the dermal temperature patch (DTP) and how to wear the monitoring belt. The devices chosen for this study include the Jonah ICTC and DTP developed by MiniMitter (Bend, OR, USA) and the Equivital EQ01 Series Life Monitor (Hildalgo Ltd., Cambridge, United Kingdom). Both devices were calibrated by the manufacturer to be accurate to ±0.1° C.

On the morning of the race, the investigators met with each subject separately at a prearranged location 2 hours before race start for ingestion of the ICTC and placement of the DTP, the chest/shoulder strap, and the sensor electronics module (SEM). Each subject's blood pressure and body mass were then recorded and once the SEM was determined to be working correctly, the athlete and their crew then proceeded to the start line. Environmental measurements

Table 2. General performance characteristics and perceptual responses of the subjects.*†

	Subject 1	Subject 2	Subject 3	Subject 4	Group mean ± *SD*	Range
Finish time (h)	35:32:54	34:51:26	34:05:25	40:51:46	36:20:23 ± 3:08:38	34:05:25–40:51:46
Average speed ($km \cdot h^{-1}$)	6.1	6.3	6.4	5.3	6.03 ± 0.50	5.3–6.4
Average heart rate ($b \cdot min^{-1}$)	102.55	110.38	111.97	102.25	106.79 ± 5.11	102.25–111.97
Aver. % exercise intensity (220-age)	61.7	61.0	61.8	56.8	60.33 ± 2.38	56.8–61.8
Maximum heart rate ($b \cdot min^{-1}$)	134.8	178.8	173.2	180.2	166.8 ± 21.51	134.8–180.2
Max. % exercise intensity (220-age)	81.2	98.8	95.7	100.1	93.95 ± 8.70	81.2–100.1
Average breathing rate ($b \cdot min^{-1}$)	36.97	35.95	37.16	36.13	36.55 ± 0.60	35.95–37.16
Blood pressure (mm Hg)	136/90	120/90	136/82	120/82	128/86 ± 9.24/4.62	120/82–136/90
CR10 maximum	9.00	9.00	7.00	8.00	8.25 ± 0.96	7.00–9.00
CR10 average	5.46	6.74	6.00	3.77	5.49 ± 1.26	3.77–6.74
RTS maximum	7.50	7.00	6.00	6.00	6.63 ± 0.75	6.00–7.50
RTS average	4.55	5.23	4.57	4.41	4.69 ± 0.37	4.41–5.23

*CR10 = Category Ratio 10 Scale; RTS = rate of thermal sensation.
†The group mean ± *SD* and range are reported.

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TABLE 3. General anthropometric changes of the subjects and the group mean ± *SD* and range.

	Subject 1	Subject 2	Subject 3	Subject 4	Group mean ± *SD*	Range
Weight (kg)						
Day prior	79.0	85.7	82.0	70.6	79.33 ± 6.43	70.6 to 85.7
Finish line	74.7	83.9	81.1	69.6	77.33 ± 6.43	69.6 to 83.9
Percent change	−5.44	−2.10	−1.10	−1.42	−2.52 ± 1.99	−1.10 to −5.44
Body water (%)						
Day prior	61.1	63.5	63.3	60.4	62.08 ± 1.56	60.4 to 63.5
Finish line	59.7	66.0	62.7	58.5	61.73 ± 3.35	58.5 to 66.0
Percent change	−2.29	3.94	−0.95	−3.15	−0.61 ± 3.17	−3.15 to 3.94
% Fat mass (scale)						
Day prior	6.6	6.7	5.2	10.3	7.2 ± 2.18	5.2 to 10.3
Finish line	7.1	4.9	5.5	17.3	8.7 ± 5.81	4.9 to 17.3
Percent change	7.58	−27.01	5.77	67.97	13.58 ± 39.59	−27.01 to 67.97
% Fat mass (calipers)						
Day prior	13.5	11.5	13.5	17.0	13.88 ± 2.29	11.5 to 17.0
Finish line	15.5	11.5	13.5	18.5	14.75 ± 2.99	11.5 to 18.5
Percent change	14.81	0.00	0.00	8.82	5.91 ± 7.25	0.00 to 14.81

of ambient air temperature, wind speed, wind direction, relative humidity, and barometric pressure measurements were recorded at the start of the race using a Professional Weather Station (Model #WS-1516U-IT; La Cross Technology, La Cross, WI, USA). The environmental measurements were taken again at 5 checkpoints and at the finish line and are summarized in Figure 1. The subjects are required by the race rules to check-in at specific checkpoints along the race course. As each subject entered the checkpoint, they were guided to our team, and the crew log sheets were collected for that portion of the race. The subject's body mass was recorded, and the SEM was exchanged for a fully charged SEM. After each subject completed the race, we again measured their body mass, percentage of body water, percentage of fat mass (scale and skinfolds), and blood pressure.

Statistical Analyses

Because of the large amount of data collected, the descriptive statistics are presented as the average (mean) with a range for all subjects. Data from the SEM data were downloaded using the "EQUIVITAL Manager v1.0" software (Hildalgo Ltd., Cambridge, United Kingdom, 2010). Conventional statistical analysis was limited due to the fact that our study had only 4 subjects. Therefore, we determined the difference between the group mean and the slowest and fastest finisher. No threshold for statistical significance was applied, as this is an observational comparison study of the sample population. A group mean was calculated and reported for each parameter. The percentage of change was found for each parameter using a simple percentage calculation. This calculation was applied to the hypothesis as follows:

$$(\text{Core Temp Subject 4} - \text{Core Temp Subject 3})/\text{Core Temp Subject } 3 \times 100 = \text{percentage of change between subjects.}$$

RESULTS

All 4 subjects of this study successfully completed the race with a mean finish time of 36:20:23 (±3:08:38) hours, placing them within the top 40% overall of the race results. As was evident on the subjects' questionnaires, all 4 runners had extensive heat and ultraendurance exercise training (the average prerace training distance was 150 $km \cdot wk^{-1}$) and 2 subjects (subjects 1 and 4) were veterans of the Badwater Ultramarathon. Our results show that the slowest runner (subject 4) attained the highest body core temperature (T°C) vs. all other subjects. Subject 4 also maintained a higher average body T°C, as compared with the rest of the sample. The temperature data that were collected for all the 4 subjects are summarized in Figure 2.

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The physiological and perceptual responses are summarized in Table 2.

The general anthropometric changes are summarized in Table 3.

Discussion

This study is unique in that selected human physiological responses were monitored throughout the entire length of an ultraendurance marathon that was 217 km long. This study is also limited in that it was conducted in a field setting with extreme environmental conditions, in which current scientific literature is limited. To our knowledge, this is the first study to record these data over this length of time under these conditions.

This study recruited 4 male athletes, with an average age of 43 (±7.35) years. All 4 subjects were able to successfully complete the race with an average finish time of 36:20:23 (±3:08:38) hours, placing them within the top 40% of the competition results. We feel that our study had a good representation of a typical competitor because every athlete on the roster had extensive ultraendurance experience. Therefore, this race typically has a very low drop-out rate (the 5 years finishing rate as of 2011 is 90.9% and in 2012, 92.7% of the field finished (2)). Also, each runner of this race is required to have a crew of at least 2 people to assist them with their needs during the event and must accompany them at all times along the race course. This also facilitated our data collection. We believe that these 2 elements allowed us to collect reliable data, as we did not have to rely on recall methods immediately after the race.

The main finding of our investigation was that the slowest subject had a higher overall core body temperature (T°C) than the other three subjects, which is contrast to reported historical findings (1,15,18,24). Original work at the Badwater Ultramarathon by Manning et al. (17) measured body T°C for 7 racers for the entire length of the Badwater Ultramarathon, of which 6 of the 7 athletes completed the race. These same investigators reported that some subjects achieved a body T°C >40.0° C and were able to successfully complete the event (17), supporting the idea that the critical body T°C of 40.0° C may not have been a factor for these athletes, as they safely finished the race. Manning et al. (17) also found that their fastest finisher attained a lower maximum body T°C (38.0° C) than those running more slowly, in which the body T°C ranged from 39.0 to 40.5° C (17).

This study found that the mean overall body T°C was 37.49° C (±0.88), and the mean maximum body T°C was 39.30° C (±0.20). Our fastest finisher achieved a mean body T°C of 36.91° C and a maximum body T°C of 39.35° C, whereas our slowest finisher achieved a mean body T°C of 38.26° C and a maximum body T°C of 39.50° C. Our results are in agreement with the findings of Manning et al. (17), in which their fastest subject achieved a lower body T°C when compared with slower finishers, who achieved a higher maximum body T°C. This investigation further examined additional parameters, in an attempt to determine what may have influenced our body T°C results.

We continued our examination by looking at skin temperature (Tsk) measurements. We found it interesting to note that subject 4 (our slowest subject) had a higher average Tsk 2.85° C higher than the rest of the group average of 31.13° C. This suggests that this subject was able to lose accumulated heat from the body's core, to the body's shell, and then to the environment, a greater thermal gradient. This finding may support the idea that subject 4 was able to tolerate the higher body T°C throughout the duration of this race, as they were able to effectively lose heat to the environment. We also examined the anthropometric measurements taken the day before the race and noted that subject 4 had a body mass that was 11.0% lower than the rest of our group (70.6 and 79.33 kg, respectively). It is also interesting to mention that this same subject had a fat mass that was 22.48% higher (17.0%) than the rest of our sample (13.88%) and ~26.0% greater than our fastest subject (13.50%). These differences in fat mass translated into a body mass index ~9.0% higher than our fastest subject. It is well known that human fat and a high body mass index act as an insulators, which may also help explain the higher body T°C (21). We also noted that subject 4 had a body surface area ~13.0% smaller than our fastest finisher. In this environment, the small body surface area may have prevented subject 4 from exchanging heat with their surroundings as effectively as someone with a larger volume of mass. It is possible that the higher body mass index combined with the smaller overall body surface area may be responsible for this subject's higher body T°C measurements. Other studies comparing body T°C and anthropometric measurements in athletes competing in ultraendurance events are limited. We found only 2 other studies and they reported no relationship between body T°C and body mass changes during Ironman distance triathlon events (14,22). In this study, we found while examining the skinfold measurements (calipers) that this measurement increased in our slowest subject, while our fastest subject's fat mass remained relatively stable. First, we could conclude that the increase in skinfold measurements was most likely due to water retention in the subcutaneous layers of the skin caused by the duration of the ultraendurance exercise, not an increase in actual body fat. In addition, these results may reveal that the energy needs for these athletes during the race may have been met by the break down of fat-free mass, rather than fat mass.

Other parameters that we examined included the rate of perceived intensity using the Borg Category Ratio 10 scale (6), and the rate of thermal sensation using the Thermal Sensation Scale (23). We found that subject 4 (our slowest finisher) had an average category ratio rating of 3.77, which is 31.33% lower than the group's average, whereas subject 3 (our fastest finisher) recorded an average category ratio rating of 6.00, which was slightly higher (8.93%) than the mean group rating overall. Therefore, subject 4 (the slowest finisher) perceived

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their overall intensity lower than the faster finishers. This may be may be the result of this subject's knowledge that they had ran this race previously at a faster pace and knew they were capable of a better performance. All of our subjects had similar thermal sensation ratings on average, which ranged from 4.41 to 5.23, which was similar to the group mean of 4.69. The rate of perceived intensity and the rate of thermal sensation did not seem to have an impact on the body T°C findings between subjects, but the results of the category ratio scale could be contributed to the fact that athletes generally adjust their effort based on previous experiences, with the unknown that lies ahead, and consciously slow their pace so they can successfully finish the race.

Our study revealed that we failed to accept our original hypothesis in which we hypothesized that the fastest finishers would demonstrate a higher body T°C vs. slower finishers. This was based on numerous previous findings. In this study, our slowest finisher achieved a higher body T°C, not the fastest finisher, as we had expected. Fat mass, body mass index, and body surface area seem to be the factors with the greatest variability in our results. However, these factors did not seem to have a detrimental effect on our slowest finisher's performance, as this subject successfully finished the race and was able to tolerate the higher T°C throughout the duration of the event, without signs of heat-related disorders. We also suspect that each subject in our study had their own unique response to the race, and therefore, our observations may support the theory that each individual may actually have their own critical T°C point.

It is clear that the needs of ultraendurance athletes are rapidly evolving and that our perception regarding body temperature response may still be unclear. A gap in the literature exists, and there is a need for further research, especially for athletes competing in ultraendurance events in extreme environments, such as the Badwater Ultramarathon.

In conclusion, this was an attempt to provide some data insight into ultraendurance performance. The conditions for data collection were challenging, and we acknowledge limitations in our work. However, this should not detract from the importance and significance of the data we did collect.

Practical Applications

This descriptive field study involving ultramarathoners performing in extreme heat supports the significance of heat acclimatization before competing in events held in hot-dry environments, as was evident in the heat training histories noted by these well-trained athletes. We recommend to sports coaches, trainers, and athletes consulting or competing in competitive ultraendurance events the following: (a) athletes performing in ultraendurance events held in extreme heat need to practice adequate heat acclimatization before competing, (b) due to the physiological changes that occur after heat acclimatization, athletes will need to make further adjustments to their training practices after acclimatization is achieved, (c) athletes should monitor their body mass before, during, and after training runs, (d) athletes need to be educated on the signs of heat-related disorders, to prevent heat-related illnesses, and finally, and (e) educate athletes, coaches, and trainers that responses during exercise in extreme heat may elicit individual responses unique to that athlete.

Acknowledgments

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