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Leonidas G. Ioannou
FAME Laboratory, School of Physical Education and Sport Science, University of Thessaly, Greece, ioannoulg@gmail.com

Lydia Tsoutsoubi
FAME Laboratory, School of Physical Education and Sport Science, University of Thessaly, Greece, lydiatsoutsoubi@gmail.com

Georgios I. Tsianos
FAME Laboratory, School of Physical Education and Sport Science, University of Thessaly, Greece, georgiosioannis@gmail.com

Andreas D. Flouris
FAME Laboratory, School of Physical Education and Sport Science, University of Thessaly, Greece, andreasflouris@gmail.com

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Psychophysical Load During the Multistage Marathon des Sables: A Case Study

Leonidas G. Ioannou[1], Lydia Tsoutsoubi[1], Georgios I. Tsianos[1], and
Andreas D. Flouris[1]

[1] *FAME Laboratory, Department of Physical Education and Sport Science, University of Thessaly, Greece*

Abstract

Introduction: This study investigated the impact of the multistage ultra-marathon event "Marathon des Sables" (MdS) performed in the Sahara Desert on the psychophysical capacity of an athlete. **Methods:** We collected and analyzed environmental, physiological, and behavioral data from a 39-year-old athlete who participated in the MdS. Specifically, we collected environmental temperature (T_{env}), upper inguinal skin temperature (T_{sk}), heart rate, and running speed data. Also, we recorded blood glucose and lactate, thermal comfort, total body water, perceived exertion, and cognitive function at the start, middle, and the end of each race stage. **Results:** We found significant detrimental impacts on the health and wellbeing of the monitored athlete. The monitored athlete suffered a multi-toe injury during the 3rd stage of MdS. Furthermore, the T_{sk} (32.6 ± 2.6℃) fluctuated considerably between day and night, as the lowest value presented was 29.8℃ while the highest was 40.4℃. The T_{sk} tended to be higher both when the T_{env} was higher and when daily running distance was longer. Finally, the athlete's cognitive and athletic performances tended to be higher when his blood glucose (118.33 ± 19.20mg/dl) levels were higher. **Conclusion:** The health and wellbeing parameters of the monitored athlete were significantly impacted during the MdS.

Keywords: ultra-endurance, performance, desert, prolonged exercise, cognitive, injury

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Introduction

An ultramarathon race is defined as a footrace with a distance of more than 42.2 km (Baska et al., 1990; Knechtle, 2012). From a historical perspective, ancient messengers (*hemerodromes* in Greek) were the first ultramarathon runners. Herodotus wrote that one of the most well-known ancient *hemerodromes*, Pheidippides, ran more than 480 km (i.e., Sparta–Athens–Sparta) to request help from Spartans when the Persians landed at Marathon, Greece (Herodotus, n.d.). In today's time, although ultramarathon runners are not forced to run huge distances to deliver messages, ultramarathon races are becoming increasingly popular (Knechtle, 2012; Knoth et al., 2012; Tsoutsoubi et al., 2018).

A number of studies have investigated the impact of ultramarathons on human health and wellbeing. Specifically, hyponatremic encephalopathy (Clark & Gennari, 1993; Frizzell et al., 1986), reduction in left ventricular function (Scott et al., 2009), significant alterations in neuromuscular function (Millet et al., 2011), increased possibility of digestive symptoms and gastrointestinal bleeding (Baska et al., 1990), glycogen depletion (Sengoku et al., 2015), injuries/illness (Fallon, 1996; Krabak et al., 2011), and skin manifestations (Descamps et al., 2016) are some of the problems that accompany the participation to an ultramarathon. Descamps and coworkers (2016) reported that dehydration, changes in body mass, loss of skeletal muscle mass, rhabdomyolysis with renal failure, and an increase in total body water are further problems that accompany an ultramarathon. In addition to the above, athletes competing in the multistage ultramarathon Marathon des Sables (MDS) which takes place in Sahara Desert are faced with exposure to extremely high temperature and high ultraviolet radiation, as well as even higher risk of foot and toe injuries due to the desert sand entering their shoes.

The MdS is considered one of the toughest ultramarathons in the world and is held each year at the end of March or the beginning of April (Li, 2017). It takes place in the Moroccan Sahara Desert, with a maximum daytime temperature of 50℃, where multiple stages of different distances have to be completed within seven days. During the competition participants are supported with water, but have to carry their equipment including food of at least 2,000 calories per day. To increase knowledge about the impact of the MdS on athletes' health and wellbeing, this case study assessed the cognitive and physical load of the MdS on an athlete who participated in the race.

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Methods

The study was granted ethical approval by the University of Thessaly School of Exercise Science Bioethics Review Board. The participant of this study was an experienced (>100 km weekly running distance for at least the past 2 years) ultra-endurance male athlete (age 39 years; height 1.83 m; body mass 83 kg; highest previously recorded VO_2peak 81.3 ml/kg/min). He had previously completed numerous extreme ultra-endurance events including swimming the English Channel (34 km), climbing Mount Everest, and swimming across the Aegean Sea (101 km). Before the start of the study, the athlete gave his consent to be studied, and agreed to public disclosure of the results.

Eleven days before the race, the athlete followed a one-week acclimation protocol (90 minutes running per session; ~60% of VO_2peak) in an environmental chamber (43.4 ± 3.2℃, 10% relative humidity), as acclimatization can increase acclimatization can increase athletic performance by more than 10% in ultra-endurance events such as the MdS (Ioannou et al., 2018).

On the day prior to the MdS and throughout the race, we collected physiological, behavioral, and psychological data. Specifically, body composition and total body water were assessed using a body composition monitor (Fresenius Medical Care, Bad Homburg, Germany). Stature and nude body mass were measured using a stadiometer (Seca 213; seca GmbH & Co. KG, Hamburg, Germany) and a precision weighing scale (Ver. 5.3, Kern & Sohn GmbH, Balingen, Germany), respectively. Urine specific gravity (USG) was assessed using a refractometer (PAL-10S, Atago Co., Tokyo, Japan) and deemed as euhydrated (USG $\leq$ 1.02) or dehydrated (USG $>$ 1.02) based on existing guidelines (Sawka et al., 2007). Shaded (T_{env}) and nonshaded environmental temperatures were assessed using two iButton sensors (type DS1921H, Maxim/Dallas Semiconductor Corp., USA) placed on the bottom and top of the athlete's backpack, respectively. The same type of sensor was placed on the athlete's upper inguinal area to measure local skin temperature (T_{sk}). Blood lactate and glucose levels were measured using an Accutrend lactate meter (Accusport/Accutrend, Accutrend Data Corporation, Colorado, USA) and an automated analyzer (accu-chek, Roche Diagnostics Corp, Indianapolis, USA), respectively. Heart rate (HR) and running pace ($\mathrm{MdS}_{\mathrm{pace}}$) were measured using a heart rate monitor (V800, Polar Electro, Kempele, Finland). The athlete's daily diet was recorded, and no restrictions on nutritional intake were set before or during the MdS.

We measured perceived exertion using the Borg scale (Borg, 1982) as well as thermal comfort (1 = comfortable to 5 = too uncomfortable) and thermal sensation (0 = too cold to 10 = too hot). Eleven-item scales were used to assess energy availability (0: extremely low energy; 10: extremely high energy), general fatigue (0: energetic, no fatigue; 10: worst possible fatigue), and breathing difficulty (0: no difficulty at all; 10: very, very severe difficulty). Furthermore, cognitive impairment was evaluated using the 11th item from the Mini-Mental state examination test (Folstein et al., 1975). Specifically, the athlete was asked to copy an image (MM-shape) consisting of two overlapping polygonal shapes (Figure 1) on a blank piece of paper. The absolute differences between the copied MM-shapes and the original MM-shape were calculated using the following formula (where OA = overlapping shape area; A = total shape area): MM-shape difference = 100[(original OA)/(original A)] – 100[(copied OA)/(copied A)]. We used the calculated difference between the original and copied shapes to estimate the athlete's cognitive impairment.

Descriptive data analysis was used to assess the cognitive and physical load of the volunteer.

Results

During the MdS, the monitored athlete ran six stages of different lengths with a total distance of 251 km. Throughout these stages, we observed large fluctuations in psychophysical parameters (Table 1). More precisely, during the first two days of the race the studied athlete was positioned within the top 10% of the runners in the race. During the end of the second day, he injured his toes (Figure 2). The wounds on his feet became infected shortly after and he was commenced on antibiotics. Due to both the injury and infection, his running speed was reduced during

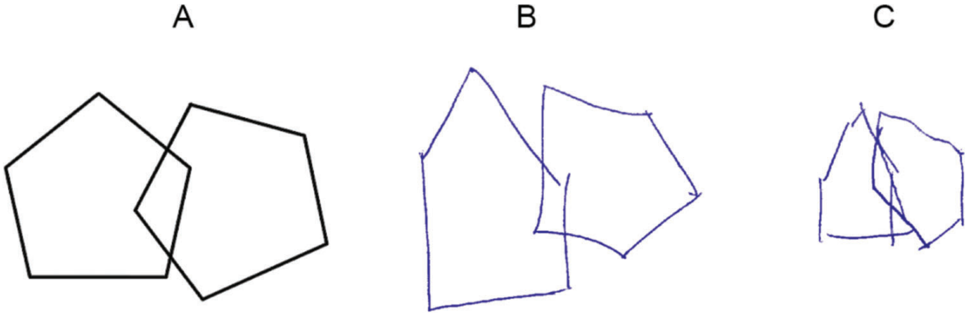

Figure 1. Copied shape from the Mini-Mental test (i.e., cognitive performance) and associated blood glucose levels of the monitored athlete. The monitored athlete had to copy the A (i.e., original shape) on a blank piece of paper. Shapes B and C represent two attempts of the athlete to copy the original shape when he had higher (148 mg/dl) and lower (81 mg/dl) blood glucose levels, respectively.

Table 1
Fluctuation in cognitive and physical indices (mean ± SD) throughout the MdS. Pre-MdS represents values prior to the race. Min and Max represent the minimum and maximum values observed during the race.

	Pre-MdS	**Min**	**Max**	**Mean ± SD**
		During the rest between the running stages		
Auditory stimuli reaction time (ms)	328	328	344	334 ± 7
Blood glucose levels (mg/dl)	123	81	148	118.3 ± 19.2
Body weight (kg)	86.9	82.8	86.9	84.6 ± 1.2
Gastrocnemius girth (cm)	40.5	39	40.5	40.0 ± 0.4
Handgrip power (kg)	49.5	46.8	51.9	49.5 ± 1.6
Lactic acid (mg/dl)	5.2	1.3	21.2	6.0 ± 5.6
Quadricep girth (cm)	53	53	55	53.8 ± 0.8
Urine specific gravity (USG unit)	1.003	1.003	1.035	1.017 ± 0.012
Visual stimuli reaction time (ms)	219	187	219	201 ± 9
Total body water (l)	55.5	45.7	55.5	51.2 ± 3.0
Intracellular body water (l)	28.3	26.0	32.7	29.2 ± 2.2
Extracellular body water (l)	22.2	19.7	23.4	22.0 ± 1.0
		During the race		
Skin temperature (℃)		29.8	40.4	32.6 ± 2.6
Heart rate (bpm)		64	167	122.5 ± 24.8
Running pace (km/h)		0	10.6	5.7 ± 2.7
		During the competition: both during the race and rest		
Breathing difficulty	0	0	8	3.2 ± 3.2
Energy availability	6	1	8	4.1 ± 2.2
General fatigue	2	2	10	7.4 ± 2.4
Perceived exertion	6	6	19	13.7 ± 5.1
Thermal comfort	3	1.5	5	3.4 ± 0.9
Thermal sensation	2	2	9	5.3 ± 2.7

Figure 2. Athlete’s toes after the third stage of the MdS.

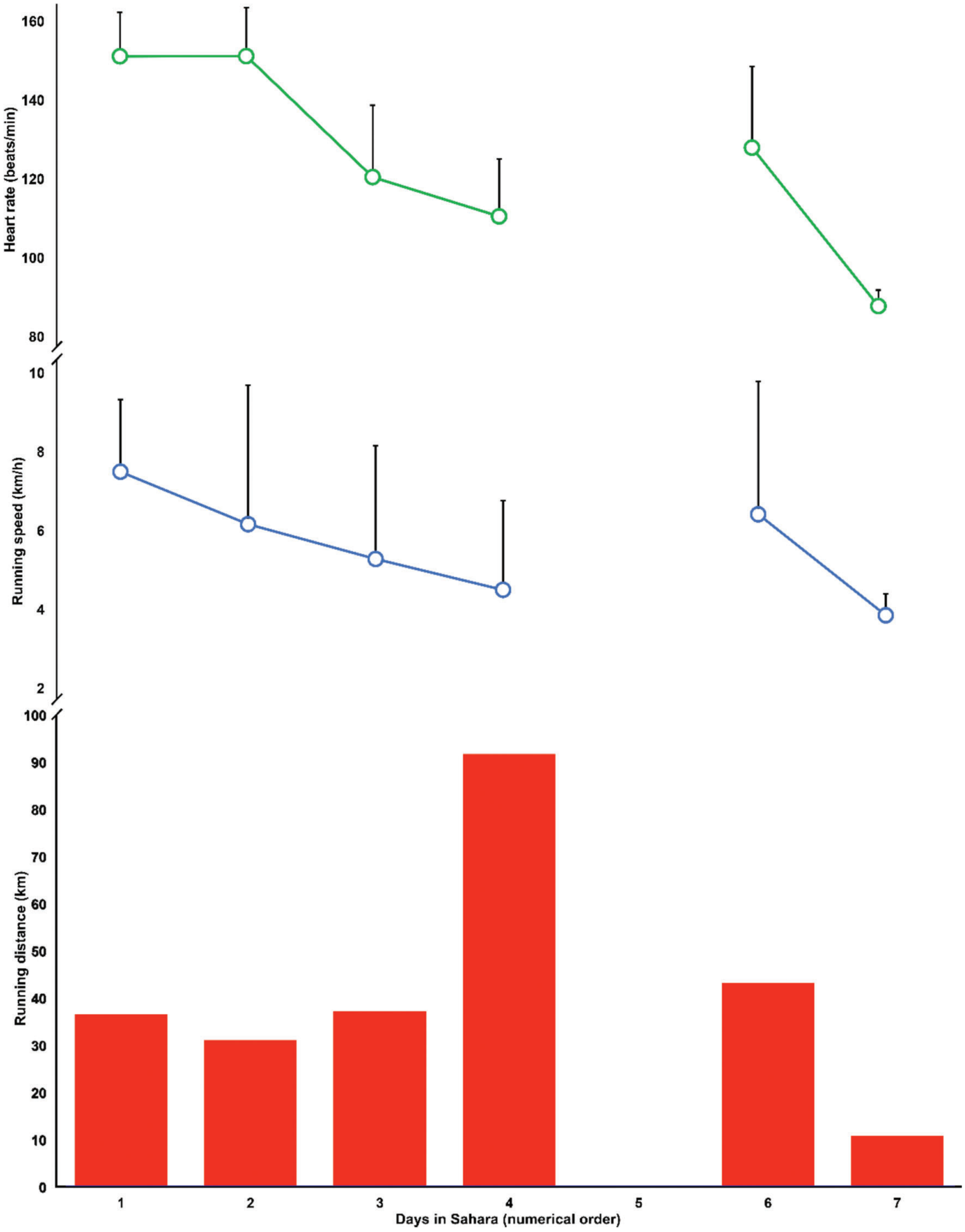

Figure 3. Effect of daily running distance on the running speed and heart rate of the monitored athlete. Green and blue lines indicate the heart rate and running speed (mean ± SD) during the race, respectively. Bars represent the daily running distance during the MdS. Note: the athlete did not compete during the fifth day, as all athletes were given 2 days to complete the 92 km on the fourth day, and he completed the entire distance non-stop in ~19 hours.

the remainder of the race (Figure 3) and therefore his final overall position dropped to the 323rd place (i.e., within the top 25%) out of 1328 athletes.

Throughout the race, T_{env} (26.5 ± 6.2℃) ranged from 13.6℃ at night to 49.6℃ during the day. Due to this fluctuation in T_{env}, the athlete's T_{sk} (32.6 ± 2.6℃) showed large variation as well (Figure 4). Specifically, his T_{sk} tended to be higher during exposure to high T_{env}, while it was decreased at lower T_{env} (Figure 4). Also, we identified a tendency of T_{sk} to be elevated when the athlete covered longer distances during the day. By contrast, data concerning heart rate do not seem to be related to the

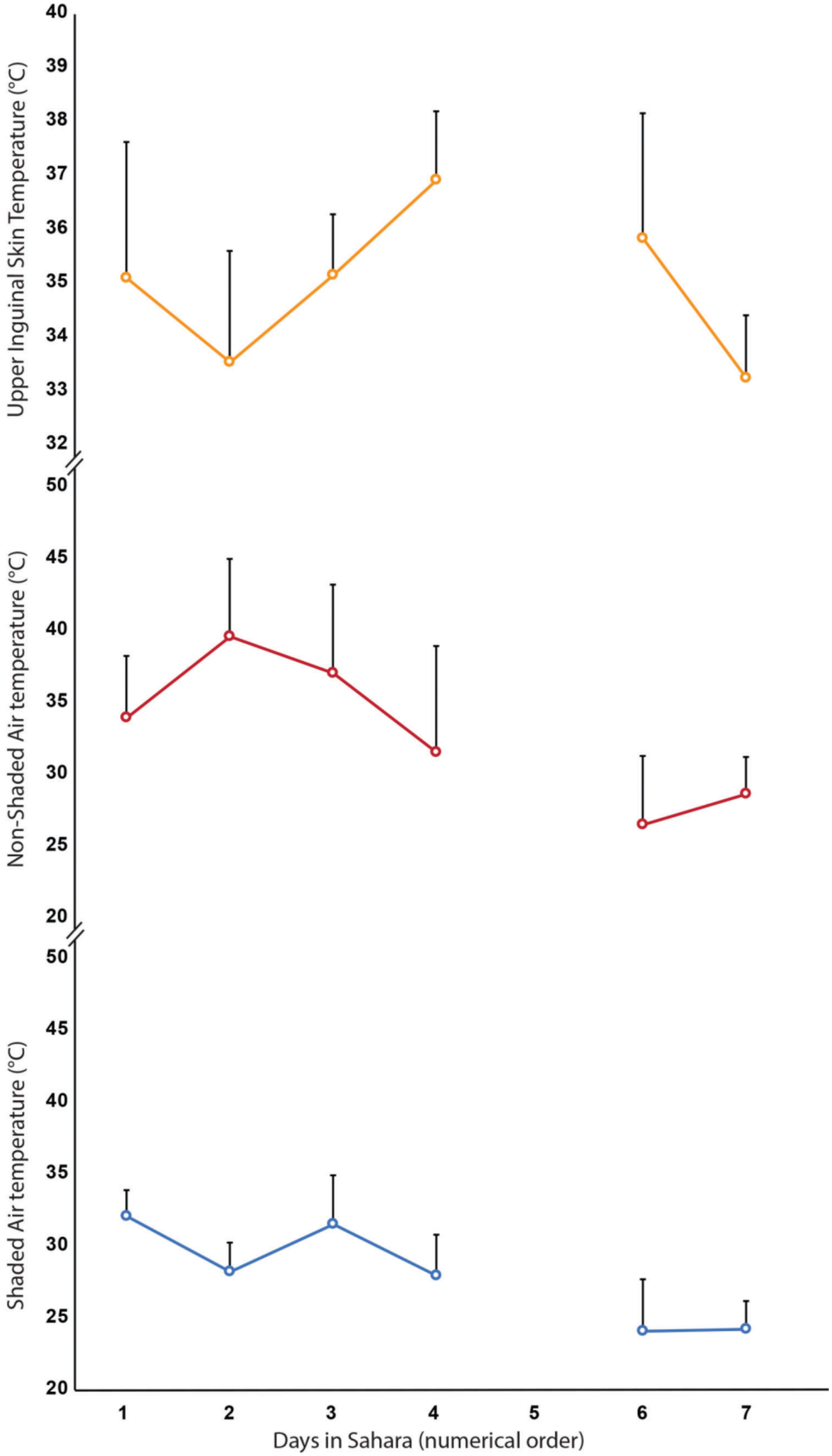

Figure 4. Core and ambient temperatures (mean ± SD) of the monitored athlete during each day of the MdS race.

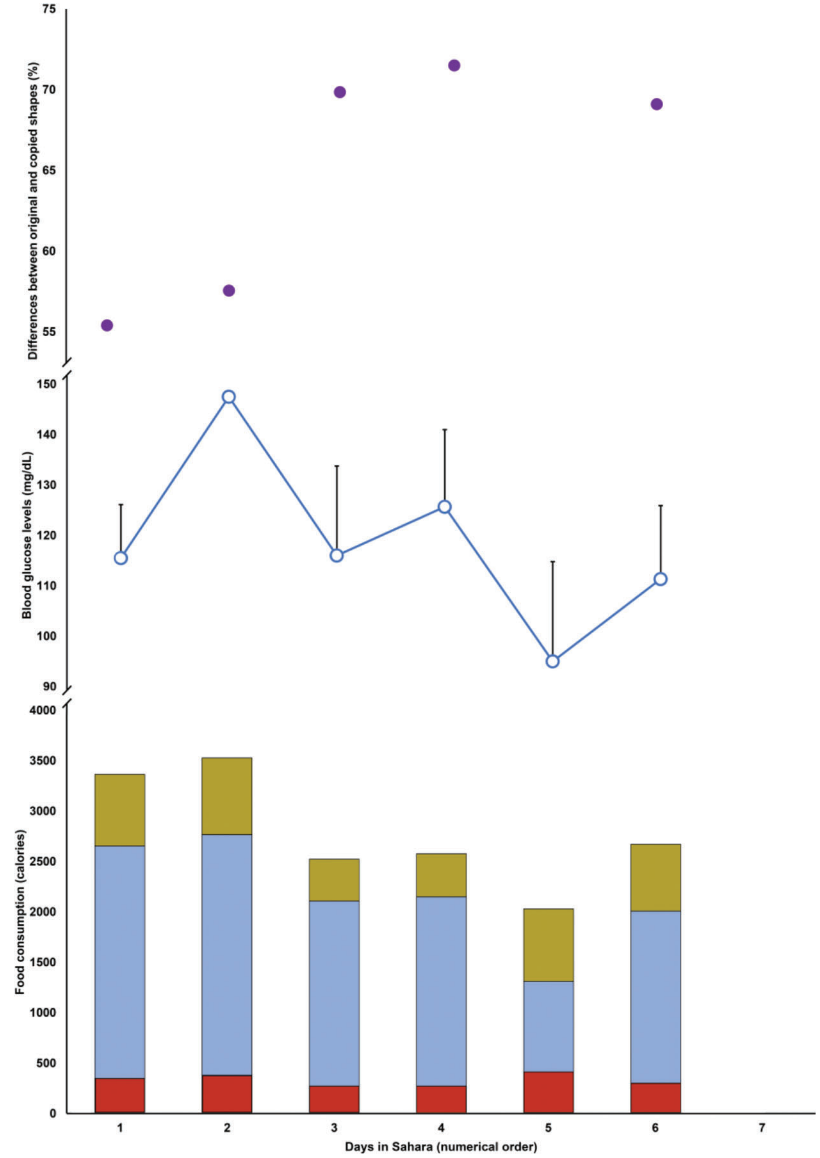

Figure 5. The athlete's calorie intake, blood glucose levels (mean ± SD), and cognitive performance during the MdS. Dots represent the cognitive performance (i.e., differences from the original shape). Bars represent the athlete's daily nutritional intake (yellow: fat; blue: carbohydrate; red: protein). No bars indicate no food consumption during the seventh day.

daily running distance, but they seem rather to be higher during the first days compared to the last days in the MdS (Figure 3). This was due to the above-mentioned injury that the athlete suffered, which affected his running speed.

As expected, the athlete's carbohydrate and vitamin intakes were increased during days of high total food consumption. Furthermore, the daily carbohydrate intake was linked with the average daily blood glucose level (Figure 5). Also, blood glucose levels were linked with cognitive performance (Figure 5), whereby a more accurate copy of the MM-shape was obtained during periods of higher blood glucose levels (Figures 1 and 5). Subjective thermal comfort and thermal sensation were linked with perceived exertion, breathing difficulty, general fatigue, and energy availability.

Discussion

To our knowledge, this is the first study that has assessed both the cognitive and physical load of the MdS on an athlete who participated in the race. According to our observations, there were detrimental impacts on cognitive and physical indices and, consequently, athletic performance and health of the observed athlete. Specifically, despite being well-trained (i.e., two years of focused MdS training) and heat-acclimatized (i.e., one-week acclimation protocol before the MdS), the majority of the athlete's cognitive and physical indices demonstrated marked unfavorable changes.

Although it is well known that the human capacity to perform prolonged exercise/work is reduced in the heat (Flouris, 2011; Flouris & Schlader, 2015; Flouris et al., 2018; Ioannou et al., 2017; Nybo, 2008), there is a lack of studies describing this association during multistage ultra-endurance events lasting seven days or longer. Therefore, our analysis focused on identifying trends in physiological strain and investigating their relationship with athletic performance. In this light, we showed that T_{sk} is an important modifier of thermal comfort and consequently of athletic performance during running an ultramarathon in the heat. This finding is in line with previous studies reporting that environmental heat stress increases human T_{sk} (Ioannou et al., 2017, 2019), leading to a voluntary reduction in exercise/work intensity (i.e., self-paced exercise) (Ioannou et al., 2017; Sawka et al., 2012), which is one of the most sensitive behavioral responses during exercise in the heat. However, despite the fact that behavioral thermoregulation is a principal factor which determines athletic performance in the heat (Flouris & Schlader, 2015), the possibility of an injury or the lack of food during ultramarathon events is even more important for a successful finish. More precisely, previous studies reported that during an ultramarathon the risk of injury and/or illness is extremely high (Fallon, 1996; Krabak et al., 2011). Specifically, Fallon (1996) reported that 72% of the ultramarathon athletes who participated in the Sydney to Melbourne ultramarathon reported at least one injury. A more recent study reported that 85% of the monitored athletes required medical care more than three times on average throughout a seven-day ultramarathon, such as the MdS (Krabak et al., 2011). Under these circumstances, it was not surprising that the monitored athlete in this study was injured. Specifically, during the second day of the MdS the monitored athlete injured his toes. He managed to finish the stage; however, the wounds sustained became infected shortly after. The combination of multi-toe injury and infection was the main reason why his running speed during the second half of the race was much slower compared to the first days in the MdS.

Food consumption was another factor that affected the athlete's athletic and cognitive performance during the MdS. More precisely, his blood glucose levels were significantly elevated after consumption of a high-carbohydrate snack, and due to this, his athletic and cognitive performances were increased as well. These results are in line with previous studies suggesting that higher blood glucose levels may lead to increased cognitive performance (Scholey et al., 2001). Therefore, glycogen depletion could be a factor of physical and mental fatigue during the MdS.

In conclusion, participation in the MdS led to increased cognitive and physical stress for the monitored athlete. Although our participant was an experienced and well-prepared athlete, we identified that both his physiological and cognitive performances were impaired due to the extreme environmental and physiological stress accompanying participation in the MdS. This highlights the need for appropriate guidance for those who wish to participate in such events.

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