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Habitual Heat Exposure and Acclimatization Associated with Athletic Performance in the Multistage Marathon des Sables

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Abstract

Introduction

The aim of this study was to investigate the impact of heat acclimatization on athletic performance during the 7-day Marathon des Sables (MdS) which takes place in the Sahara Desert.

Methods

Anonymous data for nationality and average running speed (km/h) of all runners who ran the MdS during the period 2000–2015 were collected from the official website of the race and other related websites. Average maximum temperature for each runner's country during the month preceding the MdS was collected from www.weatherbase.com. Athletes were divided into two T_{origin} groups as follows: −5 to 15℃ (i.e., cold countries) and 15 to 35℃ (i.e., warm countries).

Results

Overall, 12 467 (10 828 men; 1639 women) athletes from 78 countries (37 cold; 41 warm) participated in the MdS during the 16-year study period. The ambient temperature of these countries one month prior to the MdS ranged from −4.2 to 34.4℃. Athletes' average running speed during the MdS ranged from 2.9 to 13.4 km/h. Moreover, athletes who originated from warm countries ran the MdS 10.7% faster compared to athletes from cold countries.

Conclusion

The natural heat acclimatization achieved by living in warmer countries seems to provide an advantage during the MdS.

Keywords: ultra-endurance, running speed, heat, performance, desert

Introduction

The Marathon des Sables (MdS) is considered as one of the toughest ultra-endurance races in the world (Geddes, 2007). It takes place annually in April in the Moroccan desert, where maximum daytime temperature reaches 50℃. The race includes multiple stages of different lengths (10–92 km) to be completed within 7 days. Throughout the MdS, participants are supported with 4.5 L of water rations daily, but have to carry their own food and equipment. A previous study showed that athletic performance during the MdS is affected by several factors including age, sex, and nationality (Knoth, Knechtle, Rüst, Rosemann, & Lepers, 2012). While the physiological impact of age and sex during exercise in hot environments is well established (Flouris & Piantoni, 2015; Stapleton et al., 2014, 2015), the impact of nationality and, hence, the habitual experience with heat stress remains unclear. Several case reports in the literature suggest that athletes' origin may impact athletic performance (Carrillo, Koutedakis, & Flouris, 2011; Lucia et al., 2006; Onywera, Scott, Boit, & Pitsiladis, 2006; Scott & Pitsiladis, 2007). However, the available genetic studies do not confirm that a unique genetic makeup can explain this relationship (Scott & Pitsiladis, 2007). Therefore, it is logical to hypothesize that natural acclimatization to the heat in athletes living in warmer countries would provide them with an advantage during races such as the MdS over athletes originating from considerably colder countries. Indeed, heat acclimation/acclimatization is a well-known major determinant of athletic performance during exercise in hot environments (Flouris & Schlader, 2015; Flouris et al., 2014; Racinais et al., 2015a). Given the abrupt transfer from cooler climates to the hot and dry environment of the Moroccan desert about 40 hours prior to the start of the race, it is logical to suspect that the impact of nationality on MdS performance reflects the degree of athletes' heat acclimatization. To explore this hypothesis, our aim was to investigate the link between the average maximum temperature at each athlete's country of origin one month prior to the MdS and the athletic performance during the MdS for all athletes that completed the event during the period 2000–2015. Our research hypothesis was that athletes originating from warmer countries would perform better in the MdS compared to athletes originating from colder countries.

Methods

Data for nationality, age, sex (provided by each athlete in their official MdS application form), and average running speed (MdS_{pace}; km/h) of all athletes who ran the MdS during the period 2000–2015 were collected from the official MdS website ("Marathon des Sables: MdS results," Accessed June 8, 2015) as well as from sports-related websites ("Atletasdelsol: MdS results," Accessed June 8, 2015; "Runraid: MdS results," Accessed June 8, 2015; "Statistik: MdS results," Accessed June 8, 2015). The MdS_{pace} was used as an indicator of athletic performance.

The average maximum temperature at the athletes' countries of origin (T_{origin}) during March (i.e., the month prior to the MdS) was collected for the 16-year study period from www.weatherbase.com. We collected the T_{origin} one month before the race because the human organism requires up to two weeks of daily exercise and/or heat stress exposure in order to be completely heat-acclimated (Kenny & Flouris, 2014).

The two databases were merged so that each athlete was associated with the temperature data of his/her country. Participants were divided into two 20-degree T_{origin} groups as follows: −5 to 15℃ (i.e., colder countries) and 15 to 35℃ (i.e., warmer countries); with two 10-degree subgroups in each T_{origin} group (colder countries: −5 to 5℃ and 5 to 15℃; warmer countries: 15 to 25℃ and 25 to 35℃). Mann–Whitney tests were used to detect statistically significant differences in age and sex between the two T_{origin} groups. Moreover, Mann–Whitney tests and effect sizes were used to identify a potential statistically significant difference in MdS_{pace} between the two T_{origin} groups, as well as between the four ambient-temperature subgroups. Chi-square tests were used to compare the ranking frequency of the first three athletes within the T_{origin} groups (i.e., how many athletes from colder and warmer countries were placed in the three first places of MdS). Statistical analyses were conducted using both SPSS v22.0 software package (IBM, Armonk, NY, USA) and Microsoft Excel (Microsoft, Redmond, WA, USA). The level of significance was set at $p < 0.05$.

Results

A total of 12 467 (10 828 men; 1639 women) athletes from 78 different countries participated in the MdS during the study period. The ambient temperature in these countries one month prior to the MdS ranged from −4.2 to 34.4℃ (Figure 1). This extended range of temperature was the main factor for the 20-degree Celsius categorization of the countries based on their ambient temperature. Specifically, 37 out of these countries were identified as "colder countries," while the remaining 41 countries were identified as "warmer countries." In total, 88% (11 016 out of 12 467) of the athletes in the MdS originated from colder countries and the remaining 12% (1451 out of 12 467) of the athletes originated from warmer countries. It is important to note that there were no differences in the age (41.9 ± 9.7 vs 41.1 ± 9.0) and sex distribution (M: 86.7%, F: 13.3% vs M: 87.8%, F: 12.2%) of the participants in the MdS between the colder and warmer countries, respectively ($p > 0.05$).

The MdS_{pace} ranged from 2.9 to 13.4 km/h. The athletes who originated from warmer countries ran the MdS 10.7% faster compared to the athletes from colder countries ($p < 0.001$) (Figure 2). A medium effect size ($d = 0.44$) was found for this comparison. Also, further analyses to identify the differences in MdS_{pace} between the four ambient temperature subgroups showed that habitual heat exposure one month prior to the MdS places a significant enhancing role in MdS_{pace} (Table 1). However, it is important to note that the 353 athletes (3.26% of all 12 467 participants in the MdS) who lived in extremely hot places (25 to 35℃ during March) may not have an advantage in the MdS (Table 1), probably because they avoid the exposure to such hot environments.

Further analysis showed that all (i.e. 100%) first and second places in the MdS during the study period were taken by athletes originating from warmer countries ($p < 0.001$). Also, 81.3% of the third places were taken by athletes who originated from warmer countries, while the remaining 18.7% were taken by athletes who originated from colder countries ($p < 0.001$).

Discussion

To our knowledge, this is the first study that investigated the hypothesis that athletes originating from warmer

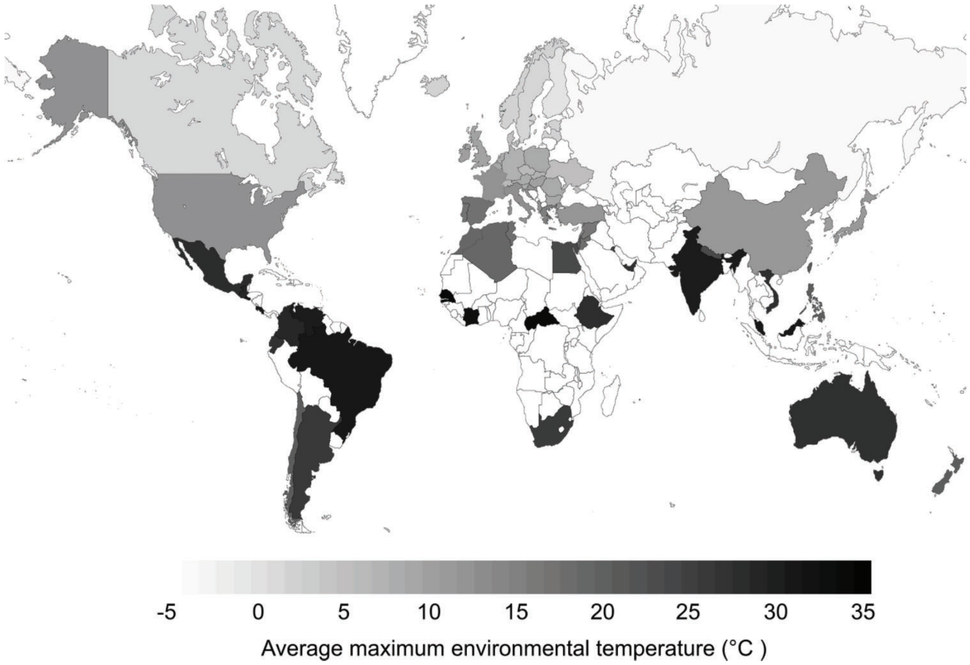

Figure 1. Average maximum temperature one month prior the Marathon des Sables of all countries with participants in the competition during the years 2000–2015. White color indicates that there were no athletes originating from these countries during the study period.

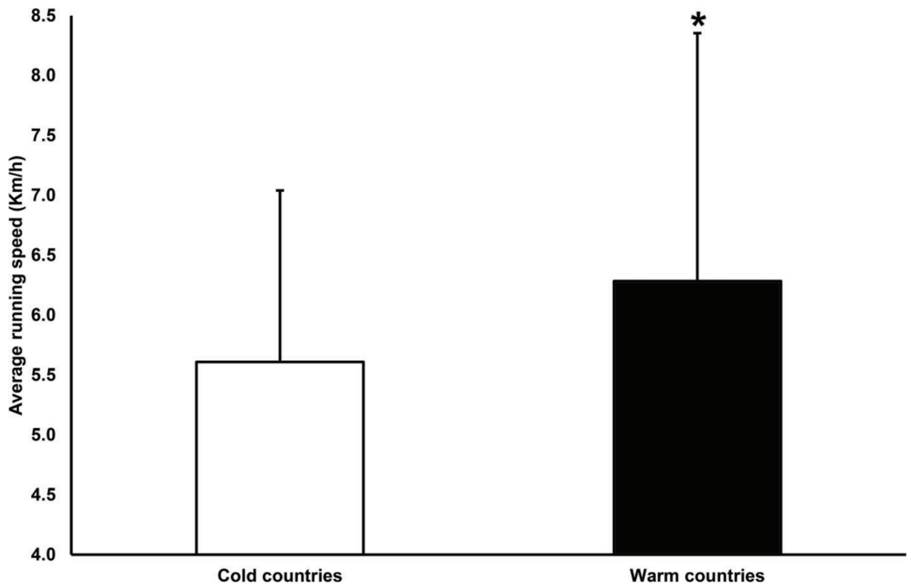

Figure 2. Differences in average running speed (mean ± SD) in Marathon des Sables between the cold and warm countries. *Statistically significant difference ($p < 0.001$).

countries perform better in the MdS compared to athletes originating from colder countries. The fact that we did not find differences in age and sex distribution (i.e., two of the main modifying factors of athletic performance in the MdS previously identified (Knoth et al., 2012)) between the warmer and colder countries allowed us to continue with further analysis and comparisons between them. According to our analysis, the main finding of the present study was the difference in MdS_{pace} between the athletes who originated from warmer and colder countries. Specifically, our results revealed that the MdS_{pace} was higher for the athletes who originated from warmer countries compared to athletes from colder countries. Also, athletes from warmer countries took the vast majority of the first three places in the MdS.

Our results are line with studies showing that heat acclimation/acclimatization can lead to improved athletic performance in the heat (Guy, Pyne, Deakin, Miller, &

Table 1
Differences in average running speed during the Marathon des Sables between the four ambient temperature categories.

	Ambient temperature categories							
	−5 to 5℃		5 to 15℃		15 to 25℃		25 to 35℃	
Ranking	N	Pace	N	Pace	N	Pace	N	Pace
Top 1%			34	10.82 ± 0.45	79	11.63 ± 0.79*		
Top 3%	9	9.40 ± 0.45	206	9.79 ± 0.79*	131	10.93 ± 1.13*†	9	9.13 ± 0.51*
Top 10%	52	8.40 ± 0.70	861	8.53 ± 0.92	254	9.67 ± 1.58*†	34	8.50 ± 0.62*
Top 20%	97	7.84 ± 0.95	1860	7.83 ± 0.95	388	8.80 ± 1.76*†	66	7.78 ± 0.9*
Top 30%	135	7.50 ± 0.93	2898	7.38 ± 1	485	8.35 ± 1.82*†	99	7.34 ± 0.98*
Top 50%	211	6.90 ± 1.12	4978	6.75 ± 1.10	672	7.64 ± 1.94*†	170	6.72 ± 1.07*
100%	408	5.72 ± 1.52	10273	5.6 ± 1.43	1042	6.53 ± 2.19*†	353	5.55 ± 1.53*

Note. "Ranking" represents the rank order of athletes based on their finish place. "N" represents the number of athletes. "Pace" represents the average running speed (km/h) of athletes.
*Significant difference from the previous ambient temperature category at $p < 0.001$
†Significant difference from the first category (−5 to 5℃) at $p < 0.001$.

Edwards, 2016; Racinais, Périard, Karlsen, & Nybo, 2015b). The interaction of the heat exposure with exercise/work leads to increased physiological strain, which has a broad range of deleterious effects in athletic/work performance (Flouris & Schlader, 2015; Ioannou et al., 2017; Périard, Racinais, & Sawka, 2015). However, it is widely accepted that humans are tropical animals and therefore able to survive and acclimatize to hot climates (Kenney, Craighead, & Alexander, 2014). In the eighth decade of the eighteenth century Lind (1771) talked about the ability of humans to adapt in hot environments. Since then, a lot of articles have been published that point out the ability of humans to adapt to the heat (Flouris et al., 2014; Périard et al., 2015). Specifically, heat acclimation is associated with physiological adaptations that are able to lead to improved thermal comfort (Gonzalez & Gagge, 1976), as well as to increased maximal aerobic capacity and consequently improved athletic performance in the heat (Lorenzo, Halliwill, Sawka, & Minson, 2010; Périard et al., 2015). The aforementioned improved athletic performance is a result of heat acclimatization responses, including increased sweating and skin blood flow responses, plasma volume expansion, better fluid balance and cardiovascular stability, a lowered metabolic rate, and acquired thermal tolerance (Périard et al., 2015).

Heat acclimatization may allow athletes to complete tasks in the heat that they are incapable of completing during acute exposure (Périard et al., 2015) or complete the task at a higher pace and hence improved performance (Racinais et al., 2015a). For instance, a study showed that only 20%, of a group of 24 subjects, were able to complete an exercise protocol of a 100-minute walk in a hot environment in the first day of heat exposure. While by the fifth acclimation day, 80% of the subjects were able to complete the same exercise session (Shephard & Astrand, 1992). Furthermore, Sawka, Young, Cadarette, Levine, and Pandolf (1985) demonstrated that heat acclimation improved VO_{2max} by 4.2% in extremely warm environments (49℃), such as the environment in which the MdS takes place every year. However, heat acclimatization progresses through regular exposure to heat (Périard et al., 2015). Specifically, it begins on the first day of heat exposure, while the benefits of heat acclimation are generally thought to be complete after almost two weeks of heat exposure (Périard et al., 2015). It is important to note that, even at the last day of the MdS, a week later, only 75–80% of the adaptations induced by natural heat acclimatization would have been completed (Pandolf, 1998; Shapiro, Moran, & Epstein, 1998). Hence, it is logical to suspect that the abrupt transfer of athletes from cooler climates to the extremely hot environment of the Moroccan desert is able to cause decline in physiological function and consequently decreased athletic performance. On the other hand, athletes originating from relatively warmer climates are already heat acclimatized on arrival and are, therefore, able to regulate more effectively their skin and core temperatures, which are the main modifying factors of the athletic performance in the heat.

The findings of the present study may be strengthened by assessing different ultra-endurance races in hot environments, and studies with physiological data such as mean skin temperature, core temperature, and heart rate should be planned in the future. Moreover, it is important to note that the categorization of athletes based on their registered home country is not the most appropriate method, as some athletes might utilize heat chambers for acclimation purposes. We believe that this limitation is, at least partly, mitigated by the large (n = 12 467) sample size of the present study; that is, while some athletes originating from colder countries may have utilized acclimation protocols, it seems logical to assume that the majority of the MdS participants analyzed would not have access to the required specialized equipment and knowledge. Also, we did not control for athletes' physical fitness level as such data were not available, but even without this important performance parameter we observed differences between groups indicating the significant impact of habitual heat exposure. Another acknowledged limitation of the study is the inability to account for the ambient temperature of the exact home and training location of each athlete, but only to divide athletes on the basis of registered home country.

Conclusion

Based on the results obtained during the course of this work, we found that athletes originating from warmer countries perform better in the MdS compared to athletes originating from colder countries. Future studies should focus on the effects of natural heat acclimatization on athletes' performance during other ultra-endurance races in hot environments.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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