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Effect of Heat and Heat Acclimatization on Cycling Time Trial Performance and Pacing

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ABSTRACT

RACINAIS, S., J. D. PÉRIARD, A. KARLSEN, and L. NYBO. Effect of Heat and Heat Acclimatization on Cycling Time Trial Performance and Pacing. *Med. Sci. Sports Exerc.*, Vol. 47, No. 3, pp. 601–606, 2015. **Purpose**: This study aimed to determine the effects of heat acclimatization on performance and pacing during outdoor cycling time trials (TT, 43.4 km) in the heat. **Methods**: Nine cyclists performed three TT in hot ambient conditions (TTH, approximately 37°C) on the first (TTH-1), sixth (TTH-2), and 14th (TTH-3) days of training in the heat. Data were compared with the average of two TT in cool condition (approximately 8°C) performed before and after heat acclimatization (TTC). **Results**: TTH-1 (77 ± 6 min) was slower (P = 0.001) than TTH-2 (69 ± 5 min), and both were slower (P < 0.01) than TTC and TTH-3 (66 ± 3 and 66 ± 4 min, respectively), without differences between TTC and TTH-3 (P > 0.05). The cyclists initiated the first 20% of all TT at a similar power output, irrespective of climate and acclimatization status; however, during TTH-1, they subsequently had a marked decrease in power output, which was partly attenuated after 6 d of acclimatization and was further reduced after 14 d. HR was higher during the first 20% of TTH-1 than that in the other TT (P < 0.05), but there were no differences between conditions from 30% onward. Final rectal temperature was similar in all TTH (40.2°C ± 0.4°C, P = 1.000) and higher than that in TTC (38.5°C ± 0.6°C, P < 0.001). **Conclusions**: After 2 wk of acclimatization, trained cyclists are capable of completing a prolonged TT in a similar time in the heat compared with cool conditions, whereas in the unacclimatized state, they experienced a marked decrease in power output during the TTH. **Key Words:** EXERCISE, HOT AMBIENT CONDITIONS, TEMPERATURE, ACCLIMATIZATION, HYPERTHERMIA, FATIGUE

In laboratory settings, cycling performance evaluated as time to exhaustion at a constant load (15,24) or as the power output maintained during a simulated time trial (TT) (12,23,24,31,32) is markedly impaired when the environmental temperature is elevated to approximately 30°C or higher. One study even indicates that performance in moderate (21°C) temperatures is impaired in comparison with that in a laboratory set to 11°C (14).

However, several factors differ between laboratory and road cycling (i.e., field) responses. Firstly, constant-load exercise does not allow for behavioral thermoregulation. Secondly, laboratory TT are performed with limited feedback (12,23,32) and sometimes for a fixed period rather than distance (12,31), failing to reproduce the competitive environment associated with an actual race. Thirdly, cycling is a relatively high-speed activity, allowing for important air movement around the athlete, which supports temperature regulation (22,28). Fourthly, even if recent studies have provided fanning to account for the thermoregulatory effect of air movement (23), the temperature of the air itself might affect the resistance for displacement during high-velocity cycling (22). For example, an increase of 20°C in ambient temperature will reduce air density by approximately 7%, allowing for an approximately 6% increase in speed for a given power output (on the basis of the assumption that 90% of the resistance is aerodynamic for an isolated cyclist).

Consequently, even if laboratory studies can characterize the physiological responses of cycling in the heat, the performance responses in a field setting require further examination. Impairments in sporting performance in hot ambient conditions have been reported from the retrospective analyses of marathon races (13) and from experimental comparison of football games in hot versus temperate conditions (20). However, these activities cannot be compared with individual cycling TT largely because of the air speed around the athlete. Indeed, although a marathon is a longer and slower activity than a cycling TT, the time of the fastest runners is less affected by the heat partially because they spend less time in the heat than slow runners (13), as they partly avoid the hot microclimate generated by large groups of runners close to each other (5,8).

In addition, although most studies are performed among participants relatively new to the testing conditions, highly

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trained athletes are more likely to specifically prepare for an important competitive event held in hot ambient conditions. Given that exercise perception and pacing is partly dependent on the previous experience of the athlete (30), cyclists might therefore adapt their pacing strategy as they get accustomed to competing in the heat and as they physiologically heat-acclimatize. To date, heat acclimatization (i.e., artificial) has been shown to increase endurance performance in laboratory cycling tests (18,21). In outdoor sports, heat acclimatization (i.e., natural) has been shown to increase the distance covered on the field during team sports activities in the heat (25,26). However, it remains unknown how pacing and performance during outdoor TT in the heat are influenced in experienced cyclists during acute exposure to heat stress and after a period of acclimatization. Moreover, it is unclear whether heat acclimatization allows to completely offset the effect of heat on exercise capacity (10,33). As such, the magnitude of performance improvement with heat acclimatization relative to the initial decrement in performance during acute exposure to heat stress remains to be determined.

Therefore, the aim of this study was to determine the effects of heat acclimatization on cycling TT performance (i.e., time, power output, and speed) and pacing strategy in hot outdoor ambient conditions. We hypothesized that hot ambient conditions would acutely impair TT performance but that the influence of these outdoor conditions would be attenuated after heat acclimatization. We further hypothesized that cyclists would adapt their pacing strategy in the heat by initiating the TT in the heat at a lower power output.

METHODS

Participants. Nine male competitive cyclists participated in this study. Their mean ± SD age, height, and body mass were 33.3 ± 7.5 yr, 184 ± 4 cm, and 77.3 ± 7.0 kg, respectively. They had a maximal oxygen consumption ($\dot{V}O_{2max}$) of 4.8 ± 0.2 L·min^{-1} (Oxycon Pro; Viasys Healthcare, Germany) with a peak power output of 418 ± 16 W (protocol, 25-W increase every minute from 100 W until exhaustion), corresponding to a performance level of 4 (i.e., well-trained cyclist (7)). All cyclists were experienced with performing TT in cold-to-temperate conditions (<25°C) and provided their written informed consent to participate in this study. The protocol conformed to the recommendations of the Declaration of Helsinki and was approved by an independent ethics committee.

The participants were Northern European residents having had no exposure to environmental temperatures above 10°C for the last 4 months before the study (i.e., November to March). They trained 14 h 40 min ± 4 h 40 min per week before the acclimatization and 13 h 1 min ± 1 h 6 min during heat acclimatization. They were encouraged to maintain a constant sleep routine throughout the protocol and remain hydrated (Table 1).

General procedure. The cyclists performed 3 TT in hot ambient conditions (TTH, see following section). The first TT in hot conditions (TTH-1) was not preceded by any outdoor riding in hot conditions; TTH-2 was preceded by 5 d in hot ambient conditions, and TTH-3 was preceded by 13 d in the heat. The participants spent a minimum of 4 h·d^{-1} outside (average temperature, 34°C ± 3°C; relative humidity, 18% ± 5%) but slept, rested, and ate indoors in an air-conditioned facility. Two additional TT were performed in a cool condition (TTC, see following section) before and after the heat intervention and were averaged to represent TTC (no difference in power output between them). Each TT consisted of completing 43.4 km as quickly as possible.

The outdoor TTC and TTH were respectively performed in Denmark and Qatar as multilap looping circuits at sea level on flat terrain (maximal elevation difference, 10 m). The TT included 24–27 turns in which no braking was required. The cyclists started at 2-min intervals to be separated across the circuit. Cyclists had 36 h (i.e., two nights) of rest after arrival in Qatar before performing TTH-1, allowing for recovery from travel fatigue. The time difference between Denmark and Qatar is only 2 h, which should not induce significant jet lag (34). On the day of the TT, the riders performed a self-paced warm-up (approximately two laps on the TT course). The cyclists were allowed to drink water and energy drinks *ad libitum* before and during the TT. During TT, the riders had access to HR, speed, distance, and power output data. This was done to simulate a TT in a normal competitive outdoor setting. Wind speed was 6.0 m·s^{-1} during TTC, and 6.8, 5.8, and 4.4 m·s^{-1} during TTH-1, -2, and -3, respectively. Environmental temperature was 8.2°C ± 3.5°C during TTC and 36.0°C ± 0.4°C, 37.4°C ±

TABLE 1. TT data.

	TTC	TTH-1	TTH-2	TTH-3	
Participants sleep and hydration					
Sleep quantity (h:min)	7:06 ± 0:45	7:11 ± 0:38	6:50 ± 0:54	7:04 ± 0:41	
Morning USG (g·mL^{-1})	—	1.016 ± 0.004	1.015 ± 0.004	1.015 ± 0.006	
Fluid consumption during TT (L)	—	0.4 ± 0.2	0.6 ± 0.3	0.7 ± 0.5	
Physiological responses					
Final rectal temperature (°C)	38.5 ± 0.6	40.2 ± 0.4	40.2 ± 0.4	40.1 ± 0.4	TTC < (TTH-1, -2, and -3)
Average HR (bpm)	166 ± 2	173 ± 1	170 ± 3	172 ± 4	
Body mass loss (%)	—	3.0 ± 0.3	2.9 ± 0.5	2.7 ± 0.5	
Performance response					
Power output (W)	304 ± 9	256 ± 19	280 ± 19	294 ± 15	TTC > TTH-3 > TTH-2 > TTH-1
Average speed (km·h^{-1})	39.4 ± 2.0	34.8 ± 2.6	37.9 ± 2.5	39.8 ± 2.3	(TTC and TTH-3) > TTH-2 > TTH-1
Time (h:min.s)	1:06.13 ± 3.26	1:17.17 ± 6.26	1:09.25 ± 4.37	1:05.37 ± 3.44	(TTC and TTH-3) < TTH-2 < TTH-1

TT were performed in TTC and in TTH-1, TTH-2, and TTH-3. Data are presented as mean ± SD. Symbols < and > show significant differences at $P < 0.05$.

0.8°C, and 36.2°C ± 1.6°C during TTH-1, -2, and -3, respectively. Relative humidity was 30% ± 8% during TTC and 13% ± 1%, 16% ± 2%, and 12% ± 3% during TTH-1, -2, and -3, respectively. On the basis of the ideal gas law ($PV = nRT$) adapted to a mixture of ideal gases (dry air and humid air), the air density (number of mol (n)/volume (V)) is inversely proportional to temperature and was calculated to be 1.249 kg·m^{-3} during TTC and 1.135, 1.127, and 1.131 kg·m^{-3} during TTH-1, -2, and -3, respectively.

Measures. Power output and speed during the TT were measured with PowerTap wheel sets (PowerTap, Madison, WI) logged continuously on Garmin devices (Garmin 705 Edge) and afterwards extracted with the software TrainingPeaks and exported in 1-Hz resolution for subsequent average by 10% of the TT. All PowerTap wheel sets were measured within 10 W from a Power2max power meter (Power2max, Berlin, Germany), and each rider used the same equipment during the TT. HR was continuously recorded during all TT via a chest strap (Polar Team System 2; Polar Electro, Kempele, Finland).

Rectal temperature was measured at the end of each TT by a clinical thermometer (precision, ±0.1°C; depth, approximately 2 cm). In addition, rectal temperature was continuously recorded during TTH-1 and TTH-3 via a telemetric sensor (precision, ±0.01°C; VitalSense; Mini Mitter, Respironics, Herrsching, Germany) inserted the length of a gloved index finger beyond the anal sphincter. Body mass losses were estimated from the changes in body weight from before to after TTH (Seca 769; Seca, Hamburg, Germany) (precision, 0.1 kg).

Statistical analyses. Continuously recorded data (power, HR, and temperature) were coded in 10% increments of the TT and analyzed via two-way repeated-measures ANOVA (four conditions × 10 times). In addition, total time was analyzed via one-way repeated-measures ANOVA. ANOVA assumptions were verified preceding all statistical analyses; logarithmic transformations and Greenhouse–Geisser corrections were applied where appropriate. In case of *post hoc* comparisons, reported P values were adjusted for multiple comparisons using a Bonferroni correction (i.e., correction for six potential comparisons between conditions). Analyses were performed in the SPSS software version 21.0 (SPSS, Inc., Chicago, IL). The level of statistical significance was set at $P < 0.05$. Effect sizes are described in terms of partial eta-squared (η^2; with $\eta^2 \geq 0.06$ representing moderate difference and $\eta^2 \geq 0.14$, large difference). Data are presented as mean ± SD along with the mean differences (95% confidence interval).

RESULTS

Performance. There was a large ($\eta^2 = 0.88$) and significant condition effect on the time to complete the TT (Table 1) ($P < 0.001$). The time to complete TTC (66 min 13 s ± 3 min 26 s) and TTH-3 (65 min 37 s ± 3 min 44 s) was not significantly different (−0.6 (−2.5 to +1.4) min, $P > 0.999$) but was significantly shorter than TTH-1 (77 min 17 s ± 6 min 26 s) and TTH-2 (69 min 25 s ± 4 min 37 s) (all $P < 0.01$). In addition, TTH-2 was significantly shorter than TTH-1 ($P = 0.001$).

Speed (Table 1) followed a similar pattern of evolution with significantly lower speeds during TTH-1 than those during TTC, followed by increases from TTH-1 to TTH-2 and from TTH-2 to TTH-3 (all $P < 0.001$). Speed during TTH-3 was similar to that during TTC (+0.4 (−0.5 to +1.7) km·h^{-1}, $P = 0.797$).

Pacing of power output. Average power output was significantly lower in TTH-1 than that in TTC (−48 (−67 to −30) W, $P < 0.001$). This decrement was partly restored after 1 wk of acclimatization (TTH-2 vs TTC, −24 (−40 to −9) W, $P = 0.003$) and further restored after the second week (TTH-3 vs TTC, −11 (−21 to −0) W, $P = 0.042$) (Table 1).

Power output decreased during the TT (Fig. 1) ($\eta^2 = 0.90$, $P < 0.001$) and showed a large ($\eta^2 = 0.51$) and significant ($P < 0.001$) time–condition interaction. The *post hoc* analysis revealed that there was no effect of condition during that first 20% of the TT (Fig. 1) (all $P > 0.05$). However, power output during TTH-1 became and remained lower than both those during TTC and TTH-3 from 30% of the distance covered onward ($P < 0.01$) and lower than that during TTH-2 from 80% onward (Fig. 1) ($P < 0.05$). Power output during TTH-2 became lower than that during TTC from 50% of the distance covered onward (Fig. 1) ($P < 0.05$). Power output during TTH-3 was lower than that during TTC in one segment of the TT only (i.e., 70%, Fig. 1) ($P < 0.05$).

HR and temperature responses. As displayed in Fig. 2, HR significantly increased during the TT ($\eta^2 = 0.67$, $P < 0.001$) relative to testing conditions ($\eta^2 = 0.24$, $P < 0.001$). The *post hoc* analysis showed that HR was significantly elevated during TTH-1 as compared with that during both TTC and TTH-3 during the first 20% of the TT (all $P < 0.05$). There were no differences between conditions from 30% onward. Consequently, HR was different between conditions ($\eta^2 = 0.41$, $P = 0.024$), without pairwise differences reaching significance (e.g., TTH-1 vs TTC, +7 (−2 to +15) bpm, $P = 0.127$;

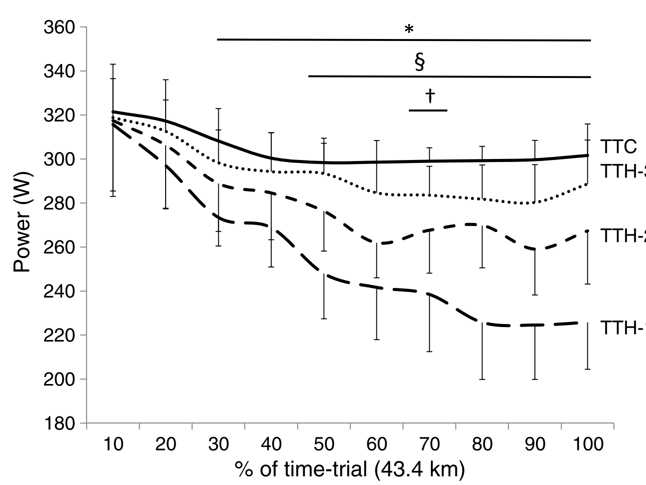

FIGURE 1—Power output during a 43.4-km cycling TT in TTC (*plain line*) and in TTH-1 (*long dashed line*), TTH-2 (*short dashed line*), and TTH-3 (*dotted line*). Data are mean ± SD. *§†TTC was significantly (P < 0.05) higher than TTH-1, TTH-2, and TTH-3, respectively.

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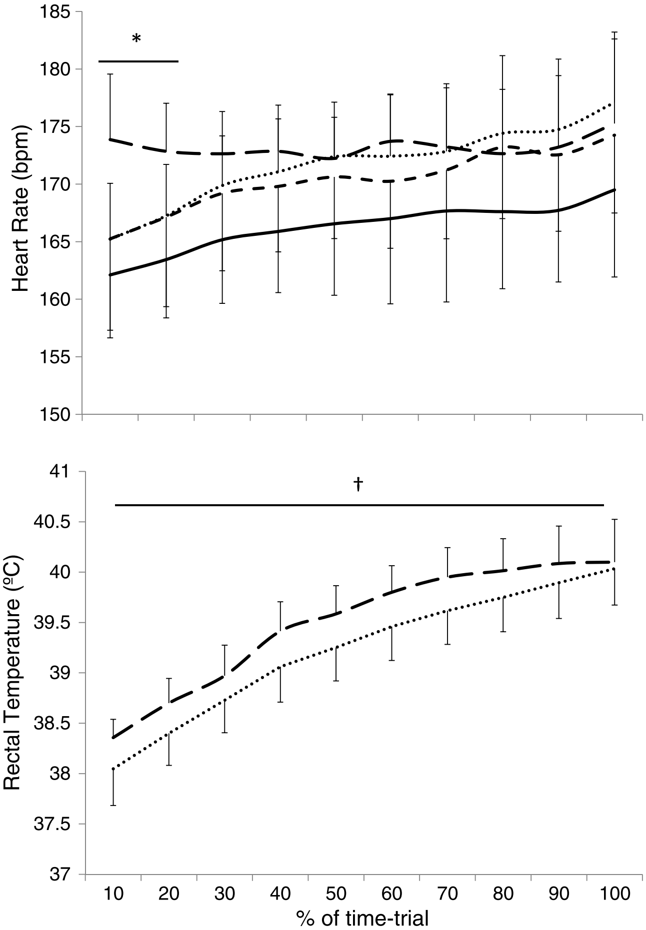

FIGURE 2—HR (upper panel) and rectal temperature (lower panel) during a 43.4-km cycling TT in TTC (*plain line*) and in TTH-1 (*long dashed line*), TTH-2 (*short dashed line*), and TTH-3 (*dotted line*). *TTH-1 > TTC and TTH-3. †TTH-1 > TTH-3; P < 0.05. NS, not statistically significant.

TTH-2 vs TTC, +4 (−4 to +12) bpm, P = 0.616; TTH-3 vs TTC, +5 (−2 to +13) bpm, P = 0.254).

Rectal temperature continuously recorded during TTH-1 and TTH-3 showed an increase during the TT (η^2 = 0.93, P < 0.001) and was higher during the first 80% of TTH-1 than that during TTH-3 (Fig. 2), leading to an overall higher temperature during TTH-3 than that during TTH-1 (+0.3°C (0.1°C–0.5°C), η^2= 0.63, P = 0.019). However, final rectal temperature (Table 1) was significantly higher after the TTH than that after TTC (all P < 0.001) (Fig. 2) but without differences between TTH (all P > 0.999). As displayed in Table 1, the differences in body mass loss (P = 0.071, η^2 = 0.28) and fluid consumption (P = 0.095, η^2 = 0.30) between the TTH did not reach significance.

DISCUSSION

The current study is the first to determine the effects of acute heat exposure and heat acclimatization on performance and pacing during outdoor cycling TT in experienced cyclists. The cyclists initiated all TT in the heat with a similar power output as maintained during the first 20% of TTC. However, while maintaining similar HR, they subsequently experienced a marked decrease in power output and speed in the heat. These decrements were progressively restored with heat acclimatization, despite core temperature in all TT in the heat increasing significantly more than that in cool conditions.

Power output and pacing. Our data showed that mean power output during TTH-1 decreased by −16% ± 5% in unacclimatized cyclists. This decrement in power output for an increase in air temperature of approximately 28°C between TTC and TTH-1 represents an average decrement in performance of −0.5% per 1°C increase. Even if this decrement is not linear, as the effect of an absolute increase in air temperature is more important in warm than in cold environments (13), this rate is comparable with the decrements reported during laboratory TT (−0.3% to −0.9% per 1°C (12,23,24,32).

In addition, the current study quantified the effects of heat stress on performance at different acclimatization stages. To date, most studies investigating the effects of heat on performance have examined unacclimatized participants. These have shown that artificial heat acclimatization increases the ability to cycle in a hot laboratory (18,21) and that natural heat acclimatization increases physical performance during sporting activities in hot environments (25,26,33). However, a comparison of the magnitude of improvement in performance after heat acclimatization, relative to the initial decrement in performance associated with the first exposure to heat stress, has yet to be examined. Our data showed that the decrement in cycling performance was progressively restored as the cyclists acclimatized. From an average power decrement of −16% ± 5% on the first day of heat exposure (TTH-1) relative to TTC, the decrement was reduced to −8% ± 4% after 1 wk of training in the heat (TTH-2) and to −3% ± 4% after 2 wk (TTH-3).

Despite the cooling effect of air movement, our data showed that the average final temperature of the riders was above 40°C during TTH, irrespective of heat acclimatization (Table 1). One rider complained of nausea after TTH-1 but did not require medical attention and participated in the following training sessions and tests without any sequelae. Despite an average final temperature of 40.2°C (range, 39.6°C–41.0°C), no athlete experienced heat-related illness after TTH-2 and TTH-3. This confirms that well-prepared athletes reach high core temperatures while exercising in the heat, asymptomatic of heat illness (4), and that there is no absolute critical temperature threshold set at 40°C (11).

In the current study, despite the decrease in power output (Fig. 1) and the possibility to drink *ad libitum* on the bike, participants lost more than 2% body mass and core temperature reached final values above 40°C in the hot conditions (Fig. 2). Our data showed a decrement in absolute intensity (i.e., power output) during the TT but the likely maintenance of a similar relative intensity. This is reflected in a similar HR after 20% of the TT (Fig. 2). Indeed, it has been shown that the rise in cardiovascular strain in hot conditions during both constant rate (1,36,37) and self-paced (24) exercise mediates a decrease in maximal aerobic capacity, resulting in an increase in relative intensity for a given absolute work rate. Although power output decreases during prolonged self-paced exercise in the heat, it is proposed that a similar relative intensity to that of cool conditions is maintained and is reflected by a similar or slightly elevated HR (24). It therefore seems that despite a decrease in power output, HR remained elevated and stable (Fig. 2). Moreover, the pacing pattern was not dependent on the environmental conditions or the acclimatization level, which is in line with recent reports that pacing strategies are not affected by environmental temperature (23), thermal perception (2), or the presence of previous muscle fatigue (6). Rather, it seems that pacing during a cycling TT in hot or temperate conditions relates to the maintenance of a physiological threshold or relative intensity (manifested by HR). Given the progressive reduction in $\dot{V}O_{2max}$ as hyperthermia develops, sustainable power output is reduced, owing to a reduction in work rate for a given relative exercise intensity (24).

Furthermore, it is remarkable that experienced cyclists started their TT at the same absolute intensity regardless of the environmental conditions or their level of heat acclimatization. Notwithstanding, it has previously been reported that TT are initiated at the same power output in hot and cool conditions (11,24,31). This similar work rate adopted seems to correspond to a critical power (16). Given that $\dot{V}O_{2max}$ does not typically decrease in the first approximately 15 min of exercise in the heat (27,29,35), athletes seem to adopt a relative intensity associated with this critical power output. As $\dot{V}O_{2max}$ progressively decreases with the development of thermal and cardiovascular strain in the heat, the maintenance of a similar relative intensity requires reduction in power output (24). However, given the role of previous experiences on pacing (30), one would expect that the large decrease in power output experienced by the athletes during TTH-1 would have led to a conservative start during TTH-2. However, our data showed that this was not the case. Initial power output was similar between trials and decreased thereafter in relation to acclimatization state. Indeed, early studies suggest that heat acclimatization attenuates the circulatory strain associated with thermoregulation (19), allowing normalization of the relation between physiological responses and work intensity (10). Consequently, the cyclists seem to have finished all TT at a similar relative intensity, as suggested by HR and the similar core temperatures recorded upon completion but at a higher power output as acclimatization progressed. Of note, the slightly higher HR in TTH may be attributable to higher skin blood flow, as suggested by the higher core temperature, although the cyclists were wearing thermal clothing in TTC, which would also have lead to increase in skin temperature and blood flow.

Effect of air density and air movement while cycling in the heat. The current study is the first to investigate cycling performance during outdoor TT in a hot environment. Previous studies have simulated TT in laboratory conditions (12,23,24,31,32). However, the evaporative capacity of the environment is improved with higher air velocities, reducing heat stress and dehydration during outdoor cycling compared with indoor laboratory-based experiments (28). In the current study, the cyclists wore thermal clothing in TTC including long tights, long sleeves, and gloves, which limited the evaporative and convective power of the environment, whereas they wore short tights and a jersey with short sleeves in the heat (except one cyclist who was consistently using white long sleeves). Therefore, it cannot be ruled out that overall performance may be optimized in a slightly warmer temperature than in the TTC conditions of the current study.

Interestingly, the detrimental effect of hot ambient conditions on speed was not as important as that on power output (Table 1). The different relations between the environment and speed and power output could be partly related to a temperature effect on air density, as the aerodynamic drag of a cyclist is related to air density and temperature (3,9,17). For example, at an air temperature of 11°C, the temperature reported to optimize laboratory cycling capacity (14), air density is approximately 1.245 $kg \cdot m^{-3}$ at sea level. In contrast, air density drops to approximately 1.165 $kg \cdot m^{-3}$ at a temperature of 30°C, reducing the drag force by approximately 6%. Consequently, the decrease in air density noted in hot ambient conditions is likely to partially attenuate the performance decrement associated with development of hyperthermia during outdoor cycling. In the current study, air density was 9.4% lower during TTH-3 (1.131 $kg \cdot m^{-3}$) than that during TTC (1.249 $kg \cdot m^{-3}$), representing a power economy of almost 8% (22). Thus, despite the slightly lower power output in TTH-3 than that in TTC (−3%), the average speeds were not significantly different.

CONCLUSIONS

This study examined the effects of hot ambient conditions on outdoor cycling TT. The novel findings of this investigation are that competitive cyclists performing an outdoor TT undertake their effort at the same power output, irrespective of the environmental conditions or previous experience. Consequently, non–heat-acclimatized cyclists are incapable of sustaining this absolute effort. However, the decrement in power output is partly recovered after 1 wk of heat acclimatization and almost fully restored after 2 wk. Furthermore, our data seem to confirm that sustainable power output is related to a given relative intensity (24), which is partly reflected in the maintenance of HR within a certain range. Finally, because of the reduction in air density associated with cycling in hot ambient conditions, speed was not different between TTH-3 and TTC.

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