Pacing adjustments associated with familiarisation: Heat *vs*. Temperate environments

(Original investigation)

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Abstract

Purpose: This study describes the effect of the initial perceptual experience from heat-familiarisation on the pacing profile during free-paced endurance time-trial (TT) compared to temperate conditions.

Methods: Two groups of well-trained triathletes performed two 20km TT's either in hot (35°C and 50% RH, N = 12) or in temperate (21°C and 50% RH, N = 22) conditions, after standardisation of training for each group prior to both trials. For both groups, TT's were separated by 11 ± 4 days, ensuring no acclimation to the conditions.

Results: Performance improvement in the heat (11 ± 24W) from the first to second trial appeared comparable to that in temperate conditions (8 ± 14W, $p = 0.67$). However, the specific alteration in pacing profile in the heat was markedly different to temperate, with a change from 'positive' to an 'even' pacing strategy.

Conclusions: Altered perceptions of heat during heat-familiarization, rather than physiological acclimatization *per se*, may mediate initial changes in pacing and TT performance in the heat, and makes familiarity with the conditions of heat of particular interest for athletes without time for sufficient HA.

Key words: hot environments; pacing strategy; familiarisation; cycling; time-trial

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Introduction

Endurance performance is reduced in the heat.[1] Compared to time-trials in temperate conditions, reductions in self-paced cycling endurance performance have been reported to be ~2%, [2] ~7% [3] and ~16% [4] for short, medium and long events, respectively. This impairment typically manifests through a progressive down-regulation of intensity (i.e. pacing); resulting in a redistribution of work in a manner that allows athletes to complete the required work in the context of the accumulating heat strain.[5] While traditional explanations for these performance reductions in the heat typically focus on physiological adjustments, contemporary models also emphasise the importance of behavioural adjustments which account for the athlete's cognitive interpretation of the environment, thermal state or perceived effort.[6]

Heat acclimatisation (HA) – i.e. undertaking repeated exercise bouts in hot environments - is commonly used to prepare athletes for endurance competitions in hot conditions.[7] Indeed, ~2 weeks of HA in well-trained cyclists has been demonstrated to offset the heat-related reductions in performance, mainly through re-establishing the pacing profile adopted to a level comparable to cool conditions.[4] Whilst it is well established that ≥14 days heat exposure is required to induce complete HA, shorter exposure periods (e.g. intermittent HA) may provide partial acclimatisation responses.[8] Indeed, it has been proposed that the adjustments in cardiovascular, metabolic, and thermoregulatory functions mediate HA according to a dose-response relationship.[9] However, despite this knowledge, the relationship between amount of heat exposure and the physiological and performance outcomes at the level of the individual athlete remains unclear.[10] For example, Keiser et al.[10] reported that the highly individual physiological responses to a training camp did not correlate to individual performance outcomes. These observations suggest that mechanisms other than physiological adaptations – such as perceptual adaptations, may also contribute to the improved endurance performance commonly observed with heat exposure.

It was recently demonstrated that the alliesthesial variations of skin temperature in response to heat stress were sufficient to alter the subjective state of the individual, and the subsequent ability to self-regulate behaviour.[11] However, of the studies that investigate HA-related effects on self-paced endurance performance, few have examined the specific role of perception in behavioural adaptations.[4,12,13] In these studies, the initial testing bouts performed in the heat were not preceded by familiarisation in thermally stressful environments. The importance of familiarisation in research studies is well established – and is essential for minimising the learning effects on outcome measures. Therefore, it is possible that the perceptual familiarisation to exercise in hot environments may influence exercise behaviour and performance, independent of the common physiological responses to HA. At present however, whilst the role of previous experience in behavioural self-regulation during exercise is often proposed to factor in acute performance improvement in the heat [14] – no studies have yet examined the importance of these factors independent of physiological responses. However, athletes without time for sufficient HA may benefit from such experience to better apprehend the specificity of heat stress during the competition.

Within this framework, the aim of this study was to determine the effect of the initial heat-familiarisation as related to perceptual experience on the pacing profile during unfamiliar free-paced endurance time-trial (TT) as compared to in temperate conditions. We hypothesized that well-trained non-HA cyclists would redistribute power output during a 20-km cycling TT performed in the heat after an initial experience in this context, while a similar population performing in temperate conditions would not alter the pacing profile.

Method

Two data sets from previous studies were used for the present work. In one study, 22 male triathletes performed repeated 20-km TT's in temperate conditions (Temperate group), while in the other study, 12 male triathletes performed repeated 20-km TT's in the heat (Heat group). Apart from the environmental conditions, there were no methodological differences between the two protocols, and as such we below describe a single experimental design.

Subjects

The two groups' characteristics are presented in Table 1. All subjects had at least 3 y of prior competitive experience, were training a minimum of 7 sessions per week, had no HA in the previous five months (commencement of both studies in February, in Paris) and were non-familiar with the specific 20-km TT. Prior to inclusion in the study, participants were medically examined by a cardiologist to ensure normal electrocardiograph patterns and obtained general medical clearance. All respective data collection was performed in accordance with the Helsinki Declaration. After comprehensive verbal and written explanations of the study, all subjects gave their written informed consent for participation in respective studies. The authors report no conflict of interest to subjects.

Experimental design

All athletes first performed a graded exercise test in thermoneutral conditions (21°C, 50% relative humidity, RH) using an electronically-braked cycle ergometer (Excalibur Sport, Lode®, Groningen, The Netherlands). The ergometer was equipped with standard 170 mm cranks and the athletes' own shoes. The positions of the handlebars and seat height were adjusted to align with those used by the athletes on their own bikes. The test was performed until complete exhaustion to determine $\dot{V}O_{2max}$ and maximal aerobic power (MAP) (Table 1).

The exercise protocol started with a 5-min warm-up at a workload of 100 W, and then increased by 20 W per minute until voluntary exhaustion. Subjects wore a facemask covering their mouth and nose to collect all expired breath (Hans Rudolph, Kansas City, MO). Oxygen and carbon dioxide concentrations in the exhaled gas were continuously measured and monitored on a breath-by-breath basis (Quark, Cosmed®, Rome, Italy). The gas analyser and the flowmeter of the spirometer used were calibrated before each test.

During the second and the third sessions, participants of the Temperate group performed a 20-km TT at 21°C, 50% RH, while subjects of the Heat group performed the 20-km TT in a climate chamber at 35°C, 50% RH (Thermo Training Room, Paris, France). There were 11 ± 4 days between each TT for each group. To ensure that performance variations during the TT's were due to experimental procedures and not to the previous training load, subjects were required to respect a 24 h rest period before each laboratory session. Sessions were scheduled at the same hour of the day.

To assure hydration status at the beginning of each session, participants were instructed to standardise the fluid consumed based on the absorption of 1L of water distributed throughout the last 2 h before the visit. At the commencement of each session, participants completed a questionnaire assessing perceived fatigue, motivation and delayed onset muscle soreness (DOMS) as based on 5-point Likert scales, and were instructed to complete the TT as fast as possible. Then, following 10 min seated period, a 15-min warm-up was completed including 10 min cycling at 100 W and 5 min at 50% of the individual's MAP. Each participant performed both the warm-up and the TT on their own bike mounted on a braked Cyclus2 ergometer (RBM GmbH, Leipzig, Germany). During the TT, convective airflow from a fan set to a standard speed (750 mm, 1450 ± 5 rpm) facing the participant was used to mimic field conditions. To control for fluid intake between sessions, the participants were instructed during the second session that they could drink *ad libitum* during the passive phase, warm-up and TT, with the volume of water ingested measured, and then replicated during the ensuing TT.

The main measurements performed during the TT protocol were the time required to complete the 20 km and the power output (PO) recorded by the Cyclus2 software at a sampling rate of 2 Hz. No feedback was provided to the subjects during TT's except for the distance remaining. The participants were not informed of their performance until the end of the study. PO values obtained for each TT were reported per km of the TT and used to show the pacing strategy.

Training load monitoring

Participants continuously recorded their usual training program during the two experiments. For three weeks before the first visit, they were equipped for each training session with a Global Positioning System monitor (Garmin Forerunner 305 GPS®, Garmin International, Inc., Kansas, MO, USA) to measure training distance and speed. Details about the training duration, intensity, mode and periodisation of the typical training week were recorded. To ensure that the training patterns applied before the two experimental sessions were similar, this training program was replicated in the seven days preceding each test.

Data analysis

Repeated measures ANOVAs were performed on PO values with Group (Heat vs. Temperate, between-subjects), Session (First vs. Second, within-subject) and Kilometre (x20, within-subject) as factors. To estimate relative changes in intensity from the PO at TT onset, the intensity at each kilometre was reported relative to the starting intensity (which was set as 100%) and used as a within-subject factor. For the psychometric and training data, the factor Session was used as within-subject factor. TT durations were compared using independent-and paired- samples t-tests for between- and within-group differences, respectively. All data were analysed using SPSS software (IBM® SPSS® Statistics 20). Planned comparisons were used in the general linear model for post-hoc analyses when differences were significant ($p < 0.05$). Effect sizes are described in terms of partial eta-squared (η_p^2, with $\eta_p^2 \geq 0.06$ representing moderate difference and $\eta_p^2 \geq 0.14$, large difference). Values are presented as means ± standard deviation (SD).

Results

Training Loads and Perceived State

No effect was observed between groups for weekly training measures volume, distance or frequency ($p > 0.10$) (Table 1). Further, no differences were evident for DOMS, fatigue and motivation levels prior to TT's ($p > 0.10$).

Power output & Pacing

A session effect ($p = 0.01$, $\eta_p^2 = 0.16$) showed that both the Temperate and the Heat group improved their performance after the first session, by 8 ± 14W and 11 ± 24W, respectively (Table 1), albeit without a group*session interaction ($p = 0.67$). However, a group*session*kilometre interaction ($p < 0.001$, $\eta_p^2 = 0.10$) revealed that in comparison to the first session, the Heat group started the second TT at a lower intensity and performed the majority of the second TT bout at a higher PO ($p < 0.05$; Fig. 1B). A group*session*kilometre*starting intensity interaction was also observed ($p < 0.001$, $\eta_p^2 = 0.08$), though there were no differences between sessions for the Temperate group relative to the starting intensity (Fig. 2A, $p = 0.89$), with only the sprint finish differing from the starting intensity (Fig 2A, $p = 0.03$). Conversely, in the Heat group PO was reduced during the first session by 21 ± 19% of the initial PO (km 15-18, *p*s < 0.001, η_p^2 = 0.57, Fig. 2B). In turn, during the second session, the Heat group demonstrated temporary increases in PO during the TT relative to the starting intensity (Fig 2B, $p < 0.05$).

Discussion

The aim of this study was to determine the effect of the initial heat-familiarisation as related to perceptual experience on the pacing profile during unfamiliar free-paced endurance time-trial (TT) as compared to temperate conditions. Although the improvement in performance (η_p^2 = 0.18) appears comparable to those occurring in temperate conditions (η_p^2 = 0.24, large size effects), the specific changes in absolute and relative pacing profiles in the heat highlight an important role for heat-familiarization. These findings suggest a specific 'immediate' behavioural adaptation evident in the heat to allow improved endurance performance prior to any likely physiological acclimatisation.

The use of a familiarization trial in research is important to reduce the influence of a repeated-bout effect (e.g. learning) biasing the interpretation of the results. Given the standardisation of training, such an outcome is likely observed in the 3.3 ± 1.2% improvement in temperate conditions, representing the TT variability due to task knowledge.[15] It was notable that despite the increased PO in the second TT, an almost identical even pacing profile existed between the initial and repeated trials in temperate conditions.[16] Similarly, the Heat group also improved TT performance as the Temperate group from the first to the second trial (5.6 ± 6.6%). However, in contrast to the Temperate group, subjects initially exposed to 35°C specifically rearranged PO distribution during the second trial in the heat to prevent the ~20% reduction in PO relative to the starting intensity. Of interest, this reduction in PO during the TT in the heat is comparable to other recent evidence of similarly trained athletes and TT's.[4] However, between the two sessions, the Heat group shifted from a positive pacing strategy to a less aggressive, more even pattern[15] characterized by a lower starting intensity (-26 ± 36W, Fig. 1B) and a steadier PO throughout the rest of the exercise bout (Fig. 2B). Such reduction of the starting intensity has previously been noticed during repeated 20km-TTs in temperate conditions, though admittedly over more trials.[17] In addition, such shifts towards an equilibrate pattern of exercise intensity has previously been reported,[4] although this was from consecutive trials prior to and following a two-weeks training camp in the heat. In part it is feasible that the initial trial was driven by a greater experience with temperate as opposed to the hot conditions. Hence, regardless of minimal familiarity with this explicit time trial, a greater familiarity with the conditions may have existed. Regardless, the altered pacing strategies and performance improvement in the heat observed in the present study (likely without HA) would suggest that heat-familiarisation-based behavioural regulation assists partially compensate for the reduction in performance due to the environmental stress.

Accepted mechanisms as to why endurance performance decrement in the heat can be minimised following HA relate to physiological acclimatization, as driven by cardiovascular, thermoregulatory and metabolic adaptations.[18,13] Complete HA has been reported to occur within 14 days of repeated exposure, though it has been shown that as little as 4-5 days can initiate 75–80% of HA adaptations.[12,20] Moreover, given that one-week intervals between heat sessions curtail physiological adaptations,[20] it is likely that the time between the heat TT's in the present study (11 ± 4 days) was sufficient for the decay of any physiological adaptations that may have resulted from the initial TT. Indeed, it has been reported that one day of HA is lost for every 2 to 5 days without heat exposure.[21,22,23] However, we must acknowledge the lack of HA measures as a limitation of this study. Nonetheless, assuming a lack of physiological HA with the ~7-15 days separating heat TT's, it is logical that the initial improvement in TT performance and altered pacing strategy are due to changes in perceptions of the heat following the heat-familiarization rather than physiological responses.

It is suggested that cognitive factors mainly account for changes in the pacing strategy. Accordingly, it is likely that the experience of the first trial in the heat provided the athletes with better information to anticipate the risks associated with an aggressive start during the second trial.[24] This greater awareness resulted in the adoption of a more even, and by virtue, potentially tolerable, pacing strategy during the second trial in the heat, as evidenced by the greater averaged PO from the first to the second session (223 ± 20W *vs* 234 ± 11W, respectively.).[25] Such reduction in initial intensity would enable a lowered rate of heat storage, subsequently preventing the precipitated physiological strain expected under these conditions. Regardless, experience is widely reported to be a powerful regulator of energy expenditure [26,27] and may explain why the Heat group demonstrated during the second trial an even strategy relative to the starting intensity (Fig. 2B), whilst still undertaking a powerful end spurt. The down-regulation of PO during the TT noted in the present study contrasts with Racinais et al.,[4] and may be explained by the fact that, the second TT of their study occurred 6 days after the daily HA commenced. It is therefore possible that in this previous study, the adaptations to the repeated heat exposures were concurrent with a familiarization effect, and therefore obscured any manifestation of heat-related perceptive adaptations on pacing adjustments during the second TT in the heat. Regardless, the current findings highlight the potential benefits of full familiarisation with the environmental conditions, and even perhaps regardless of achieving full acclimatization status if such time is not permitted.

Whilst the present study provides new information on the importance of heat familiarisation prior to endurance performance in hot conditions, some limitations need to be recognised in the current findings. Based on previous reports of decay rates of HA, the 11 ± 4 days between the two sessions should have be sufficient to allow for the decay of any substantial HA following the first TT in the heat. However, the lack of physiological measures does not allow us to fully dismiss putative cardiovascular or thermoregulatory factors in performance improvement. Such measures would enable us to consider the role of both physiological and psychological changes in performance enhancement during HA. In this perspective, future studies should address to what extent primary changes in performance following an initial exposure to the heat are associated to perceptive (e.g., rating of perceived exertion, thermal comfort) and/or cognitive (pacing template) parameters. Indeed, in regards of the highly individual variations in physiological and performance responses following HA,[7,10] the progressive development of mechanisms driving performance improvement in the heat remains to be elucidated. It must also be acknowledged that the even pacing pattern observed in the Temperate group since the first TT may partly result from the knowledge of this specific environmental conditions (i.e., 21°C). For this group, previous experience may therefore have constituted a more substantial basis than respectively for the Heat group; though this in itself is important when athletes compete in unfamiliar hot conditions.

Practical implications and Conclusion

This investigation highlights the role of heat-familiarisation during free-paced endurance TT in the heat compared to temperate conditions. We observed changes in pacing profile following a single TT in the heat, which did not occur in temperate conditions, suggesting that heat-related improvements may occur independently to physiological changes (especially since there were 11 ± 4 days separating trials). While mechanistic explanation might relate to perceptual adaptations and prior experience, further research should continue to determine the independent contributions of perceptual vs. physiological adaptations for performance improvement in the heat as part of the HA process. In this perspective, our results highlight the need for athletes without time for sufficient HA to undertake efforts in order to ensure familiarity with the conditions and reduce the uncertainty from behaviour-based outcomes that may impede performance.

Acknowledgments

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Table 1. Mean ± SD individual characteristics and data from training monitoring.
Notes. W = Watts. DOMS = delayed onset muscle soreness; Likert = extracted from Likert scales; * significantly (p < 0.05) different from the 1st session in the Heat.

Fig. 1. Absolute changes in power output per kilometre from the first to the second trial in temperate (A) and in hot (B) conditions.
Results are presented as the group mean ± SD. * significant Session effect (p < 0.05).
Notes. Temp = temperate.

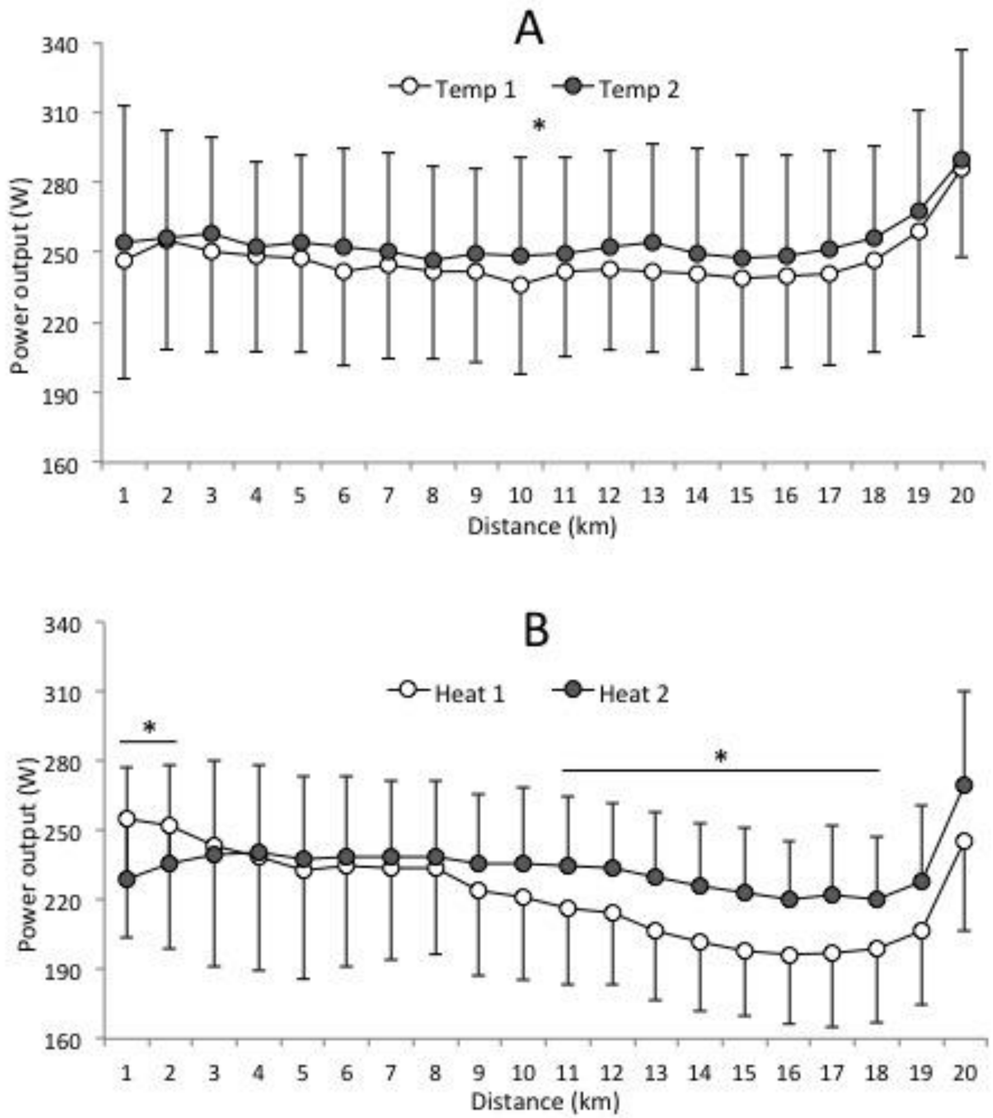
Fig. 2. Relative changes in power output from the first kilometre within the first and the second trial in temperate (A) and in hot (B) conditions.
Results are presented as the group mean ± SD. * significant differences from the first kilometre (p < 0.05).
Notes. Temp = temperate.

Table

	Variables		Temperate		Heat	
Participants	Age [y]		30.7 ± 4.4		31.6 ± 5.6	
	Height [cm]		178.8 ± 6.6		179.6 ± 5.4	
	Body mass [kg]		69 ± 7		72.7 ± 5.6	
	$\dot{V}O_{2max}$ [ml·kg^{-1}·min^{-1}]		63.3 ± 2.1		62.2 ± 3.6	
	MAP [W]		378 ± 45		390 ± 38	
			1st session	2nd session	1st session	2nd session
Training data	Training volume (min)		812 ± 119	818 ± 87	812 ± 152	831 ± 148
	Distance (km)	Cycling	259 ± 75	265 ± 73	271 ± 59	271 ± 64
		Running	34 ± 18	32 ± 16	35 ± 19	32 ± 15
		Swimming	8 ± 3	8 ± 3	8 ± 3	8 ± 2
	Frequency	Cycling	5 ± 1	5 ± 2	5 ± 2	5 ± 2
		Running	3 ± 1	3 ± 1	3 ± 1	3 ± 1
		Swimming	2 ± 1	2 ± 1	2 ± 1	2 ± 1
Testing data	DOMS [Likert]		2.4 ± 0.9	2.2 ± 1	2.3 ± 0.8	2.5 ± 0.7
	Fatigue [Likert]		1.7 ± 0.5	1.8 ± 0.4	1.8 ± 0.6	1.8 ± 0.7
	Motivation [Likert]		4.2 ± 0.4	4.1 ± 0.6	4.1 ± 1	4.0 ± 0.9
	Power output [W]		247 ± 42	255 ± 40*	223 ± 20	234 ± 11*
	Time (min.s)		32.16 ± 2.01	31.52 ± 1.37*	33.22 ± 1.58	32.40 ± 1.23*

Results are presented as the group mean ± SD.

Table 1. Mean ± SD individual characteristics and data from training monitoring.
Notes. W = Watts. DOMS = delayed onset muscle soreness; Likert = extracted from Likert scales; * significantly ($p < 0.05$) different from the 1st session in the Heat.


A
Temp 1
Temp 2
*
Power output (W)
340
310
280
250
220
190
160
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Distance (km)
B
Heat 1
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Power output (W)
340
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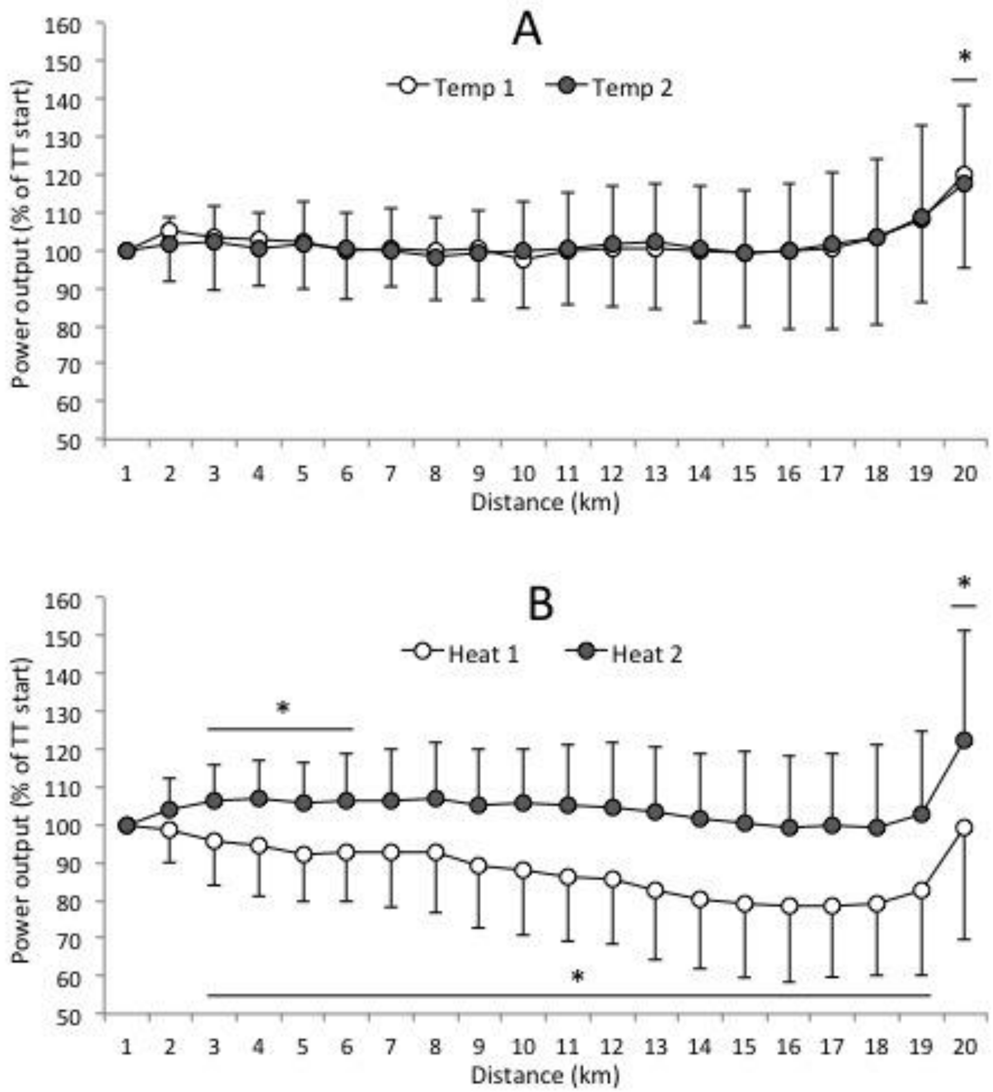
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Distance (km)

427 Fig. 1


A
Temp 1
Temp 2
*
Power output (% of TT start)
160
150
140
130
120
110
100
90
80
70
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50
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Distance (km)
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Heat 1
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Power output (% of TT start)
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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Distance (km)

428 Fig. 2