Chapter 3

Effects of radiant heat exposure on pacing pattern during a 15-km cycling time trial

Koen Levels • Jos de Koning • Iris Broekhuijzen • Tamara Zwaan
Carl Foster • Hein Daanen

ABSTRACT

Purpose

The goal of this study was to investigate effects of different durations of skin temperature manipulation on pacing patterns and performance during a 15-km cycling time trial.

Methods

Nineteen well-trained men completed three 15-km cycling time trials in 18°C and 50% relative humidity with 4.5-km (short-heat), 9.0 km (long-heat) or without (control) radiant heat exposure applied by infrared heaters after 1.5 km in the time trial. During the time trials, power output, mean skin temperature, rectal temperature, heart rate and rating of perceived exertion were assessed.

Results

The radiant heat exposure resulted in higher mean skin temperature during the time trial for short-heat (35.0 ± 0.6°C) and long-heat (35.3 ± 0.5°C) than for control (32.5 ± 1.0°C; P<0.001), whereas rectal temperature was similar (P=0.55). Mean power output was less for short-heat (273 ± 8 W; P=0.001) and long-heat (271 ± 9 W; P=0.02) than for control (287 ± 7 W) but pacing patterns did not differ (P=0.55). Heart rate was greatest in control (177 ± 9 beats·min⁻¹; P<0.001), whereas the rating of perceived exertion remained similar.

Conclusion

Radiant heat exposure and associated higher skin temperature reduced overall performance, but did not modify pacing pattern during a 15-km cycling time trial, regardless of the duration of the exposure.
INTRODUCTION

The effect of heat stress on prolonged self-paced exercise performance has been extensively studied (e.g. Marino et al. 2000; Periard et al. 2011; Altareki et al. 2009). When pacing patterns during exercise in the heat are compared with those during exercise in thermoneutral environments, the inability to maintain a desired intensity of exercise until the end frequently occurs (Tatterson et al. 2000; Tucker et al. 2004). Reductions in intensity have been reported when core temperatures were not even close to nominally critical values (Altareki et al. 2009; Ely et al. 2010). By down-regulating exercise intensity, the rise in body heat content can be blunted and the attainment of a core temperature at which body homeostasis can become compromised is delayed or prevented (Roelands et al. 2013). Both anticipation and feedback are important in the regulation of exercise intensity, in which the RPE plays a mediating role (Tucker 2009; Noakes et al. 2005; St Clair Gibson and Noakes 2004; Lambert et al. 2005). The anticipatory component is based on anticipated exercise duration, previous experience, and physiological and psychological inputs both before and during exercise, whereas the feedback component probably consists of afferent information from different physiological systems (Tucker 2009). A principal goal of this anticipatory/feedback regulation of exercise intensity is to ensure successful completion of the exercise task so as not to exceed physiological limits (Noakes et al. 2005).

When exercise is performed in the heat, signals from the thermal environment and afferent thermophysiological feedback influence the selection and modulation of intensity (Tucker et al. 2006; Marino 2004; Marino et al. 2000; Tucker et al. 2004). Skin temperature is an especially important signal since the skin is in direct contact with the thermal environment and is the main location for heat exchange between the body and the environment. High skin temperature, and more specifically, a low gradient between skin and core temperature, is associated with a high skin blood flow (Charkoudian 2003) and considerable cardiovascular strain (Kenefick et al. 2010). Moreover, high skin blood flow can compromise muscle blood flow and thereby decrease the effectiveness of exercise.
(Hettinga et al. 2007). Also, less blood is available for cerebral oxygenation (Rasmussen et al. 2010b), which can impair exercise performance as a result of decreased motor unit recruitment (Rasmussen et al. 2010a).

Precise influences of skin temperature manipulations during aerobic exercise on pacing pattern are not completely understood, especially in exercise bouts shorter than 30 min. A sudden increase in skin temperature caused by radiant heat seems not to affect pacing and performance during a cycling time trial of 7.5 km (Levels et al. 2012). However, dynamically modulating skin temperature does influence performance during 60-min cycling time trials (Schlader et al. 2011b), and early differences in the rate of rise of skin temperature have been linked to altered performance during a cycling protocol that lasts >30 min (Tucker et al. 2006). Although studies have used different protocols and different environmental temperatures, the importance of skin temperature as a physiological feedback signal during self-paced exercise differs according to the duration of the exercise. Skin temperature seems to be less important during short-duration exercise (Levels et al. 2012) but becomes more important during longer exercise bouts (Schlader et al. 2011b; Tucker et al. 2006). It should be noted that the method for inducing changes in skin temperature has an influence. Levels et al. (2012) used a radiant heat source to increase skin temperature, whereas Schlader et al. (2011b) used a liquid-perfused suit and Tucker et al. (2006) had participants exercise in high environmental temperatures. De Koning et al. (2011) compared the relative importance of physiological feedback signals in the regulation of exercise intensity to the monitoring of gauges by the driver of a race car during competition. Depending on the length of the race, different gauges become important to monitor. Accordingly, the comparatively short duration of times trial could explain why pacing patterns do not differ during 7.5-km cycling time trials with and without sudden increases in skin temperature. Moreover, it is uncertain if similar heat exposure influences pacing and performance during longer time trials when heat storage is more substantial.

Not only the length of the time trial, but also the length of the manipulation could be an important signal for the selection and modulation of intensity during self-paced exercise.
It might be that, independent of the exercise duration, the amount of disturbance in a physiological feedback signal (e.g. skin temperature) needs to reach a threshold value before exercise intensity becomes affected. This suggests that the 4.5 km of heat exposure in our previous study (Levels et al. 2012) might not have been long enough to result in power output modulations. Therefore it remains questionable if a longer exposure would have resulted in a modified exercise intensity.

To investigate whether the duration of the manipulation in skin temperature influences pacing pattern and performance during aerobic exercise, we compared the effect of two durations of radiant heat exposure on pacing pattern during a 15-km cycling time trial. We hypothesized that the longer a cyclist is exposed to radiant heat stress, the greater the down-regulation of self-selected exercise intensity will be during the trial.

**METHODS**

**Participants**

Nineteen experienced, well-trained men participated in this study (age: 24 ± 4 years; body mass: 75 ± 8 kg; height: 184 ± 8 cm; maximal oxygen consumption ($\dot{V}\text{O}_2\text{max}$): 60 ± 6 ml·kg$^{-1}$·min$^{-1}$; maximal heart rate (HR$_{\text{max}}$): 190 ± 10 beats·min$^{-1}$; peak power output (PPO): 389 ± 40 W). All participants gave their written informed consent after receiving detailed information about the study and completing a medical questionnaire including questions about exercise in the heat. The study was approved by the Human Research Ethics Committee of the faculty of Human Movement Sciences, VU University Amsterdam, The Netherlands. Participants were asked to refrain from strenuous exercise and alcohol 24 hours before each visit to the laboratory. Furthermore, all participants were asked to refrain from caffeine and heavy meals in the two hours before trials.
Incremental exercise test

On the first visit to the laboratory the participants performed an incremental step-type exercise test to volitional exhaustion. This test was conducted on a custom-made electrically-braked cycle ergometer (VU University, Amsterdam, The Netherlands) in an environmental chamber set at 18°C and 50% relative humidity (RH). After a 3-min warm-up at 100 W, the intensity of exercise was increased in a stepwise manner by 25 W every minute until volitional exhaustion. During the incremental exercise test, heart rate was recorded continuously (Polar RS400, Polar Electro Oy, Kempele, Finland) and pulmonary gas exchange was assessed breath-by-breath using a mask covering the mouth and nose, connected to a gas analysis system (Cosmed Quark b2, Cosmed S.R.L., Rome, Italy). Before the incremental exercise test, the gas analyzer (accuracy oxygen sensor: ± 0.02%; accuracy carbon dioxide sensor: ± 0.01%) was calibrated with room air and a reference gas mixture (16% O2 and 5% CO2). The volume transducer (accuracy: ± 2%) was calibrated using a 3-L syringe (Cosmed S.R.L., Rome, Italy). Maximal oxygen consumption was determined as the highest continuously recorded 30-s oxygen consumption. Intensity of exercise was recorded as power output. Peak power output corresponded to the mean power output during the last minute of the incremental exercise test. When the last minute included two exercise intensity steps (e.g. 20 s at 400 W and 40 s at 425 W), the peak value was determined proportional to the duration of these two intensity steps (within this example, this would result in a peak power output of 417 W).

Cycling time trials

At least three days after the incremental exercise test, participants performed a 15-km practice cycling time trial in 18°C and 50% RH to become accustomed to the distance and procedure of the time trial. No physiological variables were measured during the familiarization session but apart from that, the familiarization session was identical to the experimental trials. At least three days after the familiarization session, participants completed the first of three experimental 15-km cycling time trials. The time trials were performed in a counterbalanced order (as good as possible: five of the six possible trial orders were performed by three participants, one order was performed by four
Effects of radiant heat exposure on pacing pattern during a 15-km cycling time trial

participants) on a custom-made cycle ergometer (VU University, Amsterdam, The Netherlands) in a purpose-built climatic chamber set at 18°C and 50% RH, and were scheduled at least three days apart. Each trial consisted of a 20-min passive (thermal) habituation period followed by a 12-min warm-up (6 min cycling at 55% peak power output followed by 6 min at 65% peak power output). After this period, participants were given 2 min of rest after which the 15-km cycling time trial started. The participants were instructed to complete the time trial as quickly as possible and were blind to performance measurements (power output, cadence, and heart rate), but were given feedback about elapsed distance. The three experimental conditions were: no heat exposure (control), heat exposure during 30% of the time trial (short-heat), and heat exposure during 60% of the time trial (long-heat). In the heat exposure trials, radiant heat was imposed on the participants from km 1.5-6.0 (short-heat), or from km 1.5-10.5 (long-heat). Radiant heat was applied by a panel of 22 400 W ceramic infrared heaters (FSR400, Elstein-Werk, Northeim, Germany). After 1.5 km, this panel was quickly positioned in front of the cycle ergometer and after either 6.0 or 10.5 km, it was promptly removed. This resulted in a distance of either 4.5 km (short-heat), or 9.0 km (long-heat), during which the frontal surface (legs, trunk, face) of the participants was exposed to the radiation. During km 0 to 1.5, the panel was already switched on to allow sufficient time for reaching the desired radiation, but the panel was not directed at the participants. The radiation was quantified by a DRM Delta Radiometer (Helmut Hund GmbH, Wetzlar, Germany), which was positioned at a distance from the heat panel similar to the distance from the participant’s trunk to the heaters and amounted to 1100 W·m⁻². The radiant heat exposure in short-heat was identical to that used by Levels et al. (2012), whereas in long-heat, the only difference was the duration of heat exposure.

**Measures**

After arrival at the lab, participants inserted a rectal thermometer (YSI 401, Yellow Springs Instruments, Yellow Springs, OH, USA) 10 cm beyond the anal sphincter. During the trial, rectal temperature ($T_{re}$) was recorded at 10 Hz. Skin temperature was recorded at eight locations (forehead, right scapula, left upper chest, right upper arm, left lower arm, left
hand, right anterior thigh, left calf) at 0.1 Hz using iButtons (DS1922L, Maxim Integrated Products Inc., Sunnyvale, CA, USA). The iButtons were protected from direct radiation using aluminum covers and taped to the skin using Fixomull Stretch (BSN medical GmbH, Hamburg, Germany). Mean skin temperature ($T_{sk}$) was calculated using equation 3.1 (ISO9886 2004):

$$T_{sk} (°C) = 0.2 \cdot T_{left \, calf} + 0.19 \cdot T_{right \, anterior \, thigh} + 0.175 \cdot (T_{right \, scapula} + T_{left \, upper \, chest}) +$$

$$0.07 \cdot (T_{forehead} + T_{lower \, arm} + T_{left \, upper \, arm}) + 0.05 \cdot T_{left \, hand} \quad (Equation \, 3.1)$$

Heart rate, oxygen uptake, carbon dioxide production, and the respiratory exchange ratio were recorded breath-by-breath using a Cosmed Quark b^2 breathing analyser with integrated Polar radio telemetry receiver (Cosmed Quark b^2; Rome, Italy). Power output and cadence were recorded at 100 Hz. RPE was recorded every 1.5 km on a 10-point scale (Borg 1982) whereas thermal sensation and comfort were measured in the heat exposure trials every 1.5 km on a 9-point and 5-point scale, respectively (ISO10551 1993).

**Statistical analysis**

Statistical analysis was performed using SPSS statistical software (SPSS 17.0, SPSS Inc., Chicago, IL, USA). Experimental condition (control, short-heat, long-heat) was the independent variable, whereas PO, Tre, $T_{sk}$, HR, RPE, oxygen uptake, carbon dioxide production, respiratory exchange ratio, thermal sensation, and thermal comfort were the outcome measures. Means were compared using fully within-groups factorial ANOVAs (experimental condition * distance completed). Post-hoc analyses used Bonferroni correction to adjust for multiple comparisons. One-way within-groups ANOVAs compared finish times, mean PO, and magnitudes of the end spurt. Statistical significance was set at 5% for each analysis. Values are reported as mean ± SD.

To determine the practical (rather than the statistical) significance of the effects of radiant heat exposure on 15-km cycling time trial performance, 90% confidence limits of differences were identified. By comparing the overlap of these limits with the smallest
substantial and practically meaningful change in time trial performance, the chance that the observed effect was beneficial/trivial/harmful could be determined (Batterham and Hopkins 2006). For this analysis, we assume that the smallest practically meaningful change in 15-km time trial performance is 1.0% (Hickey et al. 1992; Jeukendrup et al. 1996).

RESULTS

Temperature patterns

The ambient temperature during the time trial was lower in control (17.0 ± 0.5°C) than in short-heat (18.3 ± 1.0°C) and long-heat (17.8 ± 0.7°C; P<0.05) but did not differ between short-heat and long-heat (P>0.05). The higher ambient temperature at the start of the heat exposure conditions was caused by the panel of infrared heaters that needed some time to reach operating temperature. Skin temperature patterns during the time trial are displayed in Figure 3.1. At the beginning of the time trial, $T_{sk}$ was lower for control (32.3 ± 0.9°C) than for short-heat (33.9 ± 0.7°C; P<0.001) and long-heat (33.9 ± 0.6°C; P<0.001) and this difference was maintained during the entire time trial (F=155, P<0.001). During the heat stress period (1.5-6.0 km in short-heat and 1.5-10.5 km in long-heat), $T_{sk}$ increased from 33.8 ± 0.7°C to 35.5 ± 0.9°C (P<0.001) in short-heat and from 33.7 ± 0.5°C to 36.2 ± 0.5°C (P<0.001) in long-heat. After removal of the heat panel, $T_{sk}$ decreased gradually in both short-heat and long-heat. $T_{sk}$ at the end of the time trial was higher in long-heat than in short-heat (P=0.011), whereas final $T_{sk}$ in control was lower than in short-heat and long-heat (P<0.001).
Figure 3.1 Mean skin temperature during the time trial (n = 19). Grey bars indicate the appliance of radiant heat stress during short-heat (upper bar) and long-heat (lower bar). * Higher mean skin temperature for long-heat than for short-heat (P<0.05). # Main effect between conditions (P<0.001).

Rectal temperature at the start of the time trial did not differ among the three experimental conditions (control: 37.9 ± 0.1°C, short-heat: 37.9 ± 0.2°C, long-heat: 37.9 ± 0.3°C; P=0.82). The increase in \( T_{re} \) during the entire time trial was similar (P=0.55) as well as final values (control: 39.0 ± 0.3°C, short-heat: 38.9 ± 0.3°C, long-heat: 38.9 ± 0.3°C; P=0.78).

**Time trial performance and pacing pattern**

Time to completion of the 15-km time trial differed among the three conditions (F=5.42, P=0.02). Time to completion in control (22:06 min ± 49 s) was less than in short-heat (22:32 min ± 65 s; P=0.001) and in long-heat (22:37 min ± 80 s; P=0.02). The chances that the effects of the radiant heat exposure are beneficial/trivial/harmful on the finish time of a 15-km cycling time trial in real-life competition are 0/4/96% for short-heat and 0/8/92% for long-heat. No difference was found between short-heat and long-heat (P=0.66). In line with the shorter finish time, there was a main effect of condition for power output.
Effects of radiant heat exposure on pacing pattern during a 15-km cycling time trial

(F=5.45, P=0.02). Specifically, mean power output was less for short-heat (273 ± 8 W) and long-heat (271 ± 9 W) than for control (287 ± 7 W; P=0.001 and P=0.02, respectively).

Figure 3.2 Pacing pattern during the 15-km cycling time trial (n = 19). Grey bars indicate the appliance of radiant heat stress during short-heat (upper bar) and long-heat (lower bar).

* Greater power output for control than for short-heat (P<0.05). † Greater power output for control than for long-heat (P<0.05). # Mean power output during the time trial is less for short-heat (P=0.001) and long-heat (P=0.02) than for control.

Although a main effect of experimental condition occurred for power output, pacing patterns (expressed as the interaction effect between experimental condition and distance completed) during the three trials were similar (F=0.94, P=0.55). Also the end spurt (power output during km 15 minus power output during km 14) did not differ among the trials (F=0.82, P=0.45; Figure 3.2)

Heart rate, RPE, and respiratory measures

A main effect was found for heart rate responses during the time trial (F=19.6, P<0.001). Pair-wise comparisons revealed that the mean heart rate during the time trial was less for both short-heat (172 ± 11 beats·min⁻¹) and long-heat (171 ± 11 beats·min⁻¹) than for
control (177 ± 9 beats·min⁻¹; P<0.001 for both differences). The maximum heart rate was achieved at the end of the time trial and was similar for the three conditions (short-heat: 184 ± 8 beats·min⁻¹, long-heat: 183 ± 8 beats·min⁻¹, control: 186 ± 8 beats·min⁻¹; P=0.28).

The RPE increased similarly for the three conditions during the time trial (F=2.21, P=0.12), and the average value at the end of the time trial was 9 ± 1 for short-heat, 9 ± 1 for long-heat, and 10 ± 1 for control (P=0.27).

No differences were observed in any of the respiratory measures during the time trial: oxygen consumption (F=1.21; P=0.31), carbon dioxide production (F=1.17; P=0.32), and respiratory exchange ratio (F=0.311; P=0.73) were similar for short-heat, long-heat, and control during the 15-km cycling time trials.

**Thermal sensation and comfort**

Reported values for thermal sensation and thermal comfort in the heat exposure trials are shown in Table 3.1. During km 1.5 to 6.0, when radiant heat was applied in both short-heat and long-heat, the scores for thermal sensation were greater than before this period (P<0.001). However, no differences were observed between the two conditions. During the heat exposure from km 6.0 to 10.5, when radiant heat was applied only in long-heat, thermal sensation and thermal comfort were greater for long-heat than for short-heat, indicating a warmer and more uncomfortable feeling. At the finish, the scores were similar again.
Table 3.1 Thermal sensation and thermal comfort in the radiant heat exposure trials (n=19). Underlined values indicate statistical significance.

<table>
<thead>
<tr>
<th>Period</th>
<th>Thermal sensation</th>
<th>Thermal comfort</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>short-heat</td>
<td>long-heat</td>
</tr>
<tr>
<td>Start trial</td>
<td>1 ± 1</td>
<td>1 ± 1</td>
</tr>
<tr>
<td>Heat exposure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>km 1.5-6.0</td>
<td>2 ± 1</td>
<td>2 ± 1</td>
</tr>
<tr>
<td>Heat exposure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>km 6.0-10.5</td>
<td>2 ± 1</td>
<td>3 ± 1</td>
</tr>
<tr>
<td>Finish</td>
<td>2 ± 1</td>
<td>2 ± 1</td>
</tr>
</tbody>
</table>

DISCUSSION

The purpose of this study was to evaluate the effect of two durations of radiant heat exposure on pacing and performance during a 15-km cycling time trial. The main result was that exposure and associated higher skin temperature affected overall performance but not pacing pattern, regardless of the duration of the exposure. Therefore, we have to reject our hypothesis that the longer the duration of the radiant heat exposure, the greater the negative impact will be both on pacing and performance.

The results of this study for time to completion and mean power output during the time trial support those of previous studies indicating that heat exposure decreases aerobic exercise performance in self-paced protocols (e.g. Ely et al. 2010; Peiffer and Abbiss 2011; Periard et al. 2011). However, since in our study the pacing patterns in the three trials were similar, the difference in overall performance cannot be attributed to a drop in power output during the radiant heat stress. The main determinant for the difference in finish time between the trials appears to be the approximately 20 W lower power output in short-heat and long-heat that is maintained from the start onwards, and not the radiant heat stress starting at km 1.5. Therefore, a pacing template for the time trial is constituted at the start of the trial and is based on afferent signals and expectations at that moment.
However, it has to be noted that the method used for applying heat stress in our study (radiant heat exposure) is considerably different from other studies investigating the effect of heat stress on self-paced exercise performance. Therefore, the findings of our study cannot directly be compared with results from these studies.

One factor that could have influenced the selection of a pacing strategy at the start of the time trial was the skin temperature at the start of the time trial. Because the panel of infrared heaters that applied the radiant heat stress from km 1.5 onwards needed some time to reach operating temperature, the temperature in the environmental chamber at the start of the time trial was slightly higher in short-heat and long-heat than in control, resulting in a difference in initial mean skin temperature of approximately 1.6°C. This higher skin temperature in short-heat and long-heat at the start of exercise might have affected the selection of a motor template for the upcoming 15-km time trial, possibly by anticipating a greater difficulty in heat dissipation during the time trial. This concept is supported by Schlader et al. (2011b), who concluded that skin temperature at the start of a 60-min self-paced exercise bout was important for overall performance, mainly through selection of an initial exercise intensity. Another explanation for the higher intensity from the start on might be that participants knew that they would be exposed to either 4.5 km (short-heat) or 9.0 km (long-heat) radiant heat exposure. This prior knowledge of the thermal challenge during the time trial might have influenced the anticipative component of pacing strategy that is important for the selection of the initial exercise intensity (Tucker 2009). The importance of prior knowledge of a thermal challenge during a cycling time trial is confirmed by Castle et al. (2012), who observed a higher initial power output when cyclists were deceived about the ambient temperature in which they would be cycling. They were informed that this temperature was 26.0°C instead of the actual 31.6°C. In line with this observation, Hartley et al. (2012) found no direct effect of a change in ambient temperature on power output during cycling with a fixed RPE when participants had no prior knowledge of this manipulation. All together, these observations indicate that the pacing strategy at the start of a time trial is maintained during the time trial and unaffected by a sudden heat exposure, as long as prior information is available about this thermal challenge.
Effects of radiant heat exposure on pacing pattern during a 15-km cycling time trial

Not only physiological inputs at the start of a self-paced exercise bout, but also knowledge about the length of the time trial plays an important role in the selection of an appropriate pacing strategy (Tucker 2009). Also for the effect of a skin temperature manipulation on exercise performance, the distance of a time trial might play an important role. In this study we found that a manipulation of skin temperature during the time trial is not a relevant signal for the selection and modulation of exercise intensity. This observation is in line with a previous study conducted in our lab showing that a similar manipulation did not affect pacing in a 7.5 km cycling time trial (Levels et al. 2012). In the analogy proposed by de Koning et al. (2011), the gauge ‘skin temperature’ is apparently unimportant to monitor during races up to 15 km, whereas it does appear to become more important in races of longer duration (Schlader et al. 2011a; Tucker et al. 2006), although it has also been shown that changes in skin temperature and accompanying thermal perceptions do not affect pacing pattern during a 40-km cycling time trial (Barwood et al. 2012).

We found no differences in overall performance and pacing pattern between the two trials in which radiant heat was applied (short-heat vs. long-heat). Therefore, the duration of heat exposure, and thereby the duration of the elevation in skin temperature, appears to be of no influence on performance during a 15-km cycling time trial. Although the radiant heat exposure lasted 4.5 km (approximately seven minutes) longer in long-heat than in short-heat, this did not affect pacing pattern during the time trial. Not only skin temperature was higher during km 6.0-10.5, but also thermal sensation and thermal comfort were higher during this period in long-heat than in short-heat (Table 3.1). Although Cotter et al. (2001) showed that these subjective scores may affect the motivation to continue exercise in the heat, and thereby possibly influence the selection and modulation of exercise intensity during self-paced exercise (Schlader et al. 2011a), we did not observe this in the present study. Because the pacing pattern was similar in short-heat and long-heat, the motor template that was created at the start of the time trial was maintained during the trial and unaffected by the duration of the radiant heat exposure. From a practical point of view, there is a chance of > 90%, that the radiant heat stress (and the slightly higher skin temperature at the start of the time trial) is harmful in real-life competition. This indicates that, when cycling a time trial of approximately 30 min with
solar radiation comparable to the radiant heat in this study, it is very likely that performance is negatively affected compared to conditions with minimal solar radiation (shade). Although the exercise modality used in this study was cycling, the observations might also be relevant for other exercise modalities such as running and rowing.

In summary, it seems that the motor template that is created before the start of the time trial is based on afferent signals and expectations at that moment and a sudden radiant heat exposure during the time trial does not directly affect pacing pattern. The lower exercise intensity at the beginning of the trial, likely caused by the slightly higher skin temperature at the start and/or the knowledge of the upcoming radiant heat exposure, appears to be the main reason for the observed difference in overall performance.

**CONCLUSION**

In the conditions of the present study, radiant heat exposure and associated higher skin temperature do affect overall performance, but not pacing pattern during a 15-km cycling time trial, regardless of the duration of the exposure. Initial skin temperature and prior knowledge of an upcoming heat exposure appear to be more important for the selection and modulation of exercise intensity than actual changes in skin temperature during exercise.
Effects of radiant heat exposure on pacing pattern during a 15-km cycling time trial