Pacing strategies during exercise in the heat
Levels, K.

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Aerobic exercise performance is seriously compromised in the heat. When individuals are able to self-select the intensity at which they perform exercise in the heat, both anticipation about the exercise bout and feedback from thermal afferents are important to select an initial pacing strategy at the start and to modify pacing during exercise. The main goal of this thesis is to investigate the importance of different thermal signals on the selection and modulation of exercise intensity during self-paced exercise in the heat. Moreover, the ergogenic effects of thermal interventions on performance during self-paced exercise in the heat are investigated.

In Chapter 2 an attempt was made to determine the effect of skin temperature on power output during a 7.5-km cycling time trial. To accomplish this, participants completed three short cycling time trials (7.5 km) in moderate conditions of which one without pre-cooling and without radiant heat stress during the trial, and two with radiant heat stress during the time trial, either with or without pre-cooling. The heat stress was applied by infrared heaters positioned in front of the cycle ergometer between 1.5 and 6.0 km. As expected, skin temperature was reduced by the pre-cooling and increased by the heat stress during the time trial. The pre-cooling resulted in a lower power output during the trial, whereas the heat stress did not result in differences in self-selected work rate. These findings indicate that an increased skin temperature does not affect pacing pattern during a 7.5 km time trial. The lower power output in the pre-cooling condition was likely a result of cooler leg muscles.

In chapter 2, it became apparent that skin temperature was not a relevant signal for the modulation of exercise intensity during a 7.5-km cycling time trial. However, it was still unknown to what extent the duration of the skin temperature manipulation was relevant. Therefore, the goal of Chapter 3 was to investigate the effect of two different durations of skin temperature manipulations on pacing pattern and performance during a 15-km cycling time trial. Cyclists completed three 15-km cycling time trials in moderate
conditions without or with a short (4.5 km), or a long (9.0 km) radiant heat exposure from km 1.5 in the time trial onwards. Skin temperature was higher in both heat exposure trials, whereas rectal temperature remained similar. The self-selected exercise intensity was lower in both heat exposure trials whereas the RPE was not different between the conditions. Therefore, we concluded that a 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.

In contrast to the preceding chapters, not thermal signals during exercise, but signals before the start of exercise were manipulated in Chapter 4. Because the best way to apply pre-cooling for endurance exercise in the heat is still unclear, the effects of different preparation regimes on pacing during a 15-km cycling time trial in the heat were determined. Participants completed four 15-km time trials in 30°C, preceded by four different preparation regimes: 10 min cycling; 30 min scalp cooling of which 10 min cycling; ice slurry ingestion; 30 min scalp cooling and ice slurry ingestion. The main goal of the ice slurry ingestion was to lower the core temperature, whereas the main objective of the scalp cooling was to lower the skin temperature of the scalp and thereby thermal sensation. The rectal temperature during the initial kilometers of the time trial was lower for both ice slurry time trials and this was accompanied by a greater sensation of coolness. In these trials, a higher power output towards the end of the time trial was found, but this did not lead to different finish times. Therefore the preparation regime providing the lowest body heat content and greatest sensation of coolness at the start (scalp cooling + ice slurry ingestion) was most beneficial for pacing during the latter stages of the time trial, although overall performance did not differ.

In Chapter 5, not physiological components that may influence pacing, but psychological signals were manipulated. Although cooling during exercise in the heat has been shown to be beneficial for performance, it remains unclear to what extent this effect can be contributed to actual physiological or perceptual changes and to what extent the expectation of receiving cooling plays a role. Therefore, main goal of this chapter was to investigate the effect of false information about receiving cooling on performance and
pacing pattern during a 20-km cycling time trial in the heat. Participants completed three 20-km cycling time trials in the heat. The first and second time trial involved cycling with or without wind cooling from km 7-13, whereas in the third trial participants were deceived about receiving cooling during the trial: false-positive (expectation = cooling, reality = no cooling) or false-negative (expectation = no cooling, reality = cooling). During and after cooling, skin temperature and thermal perceptions were lower in the trial with wind cooling than without wind cooling and power output was higher during the entire time trial. In the false-negative trial, physiological parameters followed a pattern similar to the trial without wind cooling. Also, the pacing pattern prior to the wind cooling was similar to the trial without wind cooling, but at the (unexpected) start of the wind cooling it appeared to switch over to the pacing pattern in the trial with wind cooling. After the cooling, no differences in pacing pattern were found between conditions. In the false-positive expectation, no differences in pacing pattern were observed despite higher skin temperature and thermal perceptions. It was concluded that deceiving participants about the occurrence of convective cooling during self-paced exercise alters the pacing pattern of a 20-km cycling time trial in the heat. This shows the importance of expectations regarding thermal load in self-paced exercise. Therefore, it is important that researchers should always account for psychological effects when applying a physiological intervention.

Chapter 6 focused on the effect of hydration status at the start on pacing and performance during a 40-km cycling time trial in the heat. Although the separate effects of heat and hypohydration on self-paced exercise performance have been studied extensively, their interactive effect is relatively unknown. Therefore, the purpose of chapter 6 was to determine the combined effect of hypohydration and heat stress on pacing pattern and performance during a 40-km cycling time trial. Participants completed four 40-km cycling time trials in 25°C or 35°C, in euhydrated and hypohydrated conditions. In all the trials, there was a facing air flow that closely resembled outdoor conditions. Hypohydration was induced before starting the time trial by 50 min exercise in hot and humid conditions and resulted in a loss of 1.2% of body mass at the start of the time trial. Heat stress increased finish time whereas a trend was observed for hypohydration. No
interaction effect between heat stress and hydration status on finish time was found. Moreover, heat storage, skin temperature, thermal sensation/comfort and RPE were higher in the hot trials, whereas thirst sensation was higher in the hypohydration trials. Based on these results, it is concluded that the negative effect of hypohydration on exercise performance during a 40-km cycling time trial is similar in hot and moderate conditions. Probably, the cooling provided by the high air velocity prevented hypohydration from becoming a performance limiting factor.

The purpose of Chapter 7 was to investigate if drinking ad-libitum during exercise could counteract potential negative effects of a hypohydrated start during a 40-km time trial in the heat. The data used in this chapter were part of the dataset that was used in chapter 6, although not all the experimental trials used in chapter 6 are used in chapter 7 and vice versa. Participants performed one 40-km cycling time trial in the heat euhydrated and two trials in the heat hypohydrated. During one hypohydrated trial, they were not allowed to drink, whereas during the other trial, ad-libitum water ingestion was allowed. All the time trials were performed in hot and humid conditions. Prior to the start of the time trial, body mass was 1.2% lower in the hypohydrated trials compared to the trial in which euhydration was maintained. During the trial, the drinking resulted in a less substantial body mass loss. The difference in hydration status at the start as well as the drinking during the trial had no effect on pacing and performance or on any physiological parameters. Since hypohydration did not adversely affect exercise performance during a 40-km cycling time trial in the heat, whether or not participants drank during exercise could not influence their performance.

In Chapter 8, not athletes but firefighters are used as study population. Main reason for this is that firefighters are often exposed to severe heat stress whereas their performance, similar to athletes, needs to be optimal. As firefighters often perform tasks in the firehouse that may increase their body temperature, this pre-warming may impair subsequent performance. Therefore, the goal of this chapter was to examine the effect of active pre-warming on speed and quality of performance during simulated firefighting exercise. Twelve male firefighters performed two trials in counterbalanced order. They
were either pre-warmed by 20-min cycling exercise or sat in a chair for 20 minutes (thermoneutral control condition). Compared to the thermoneutral conditions, the pre-warming increased gastrointestinal temperature, skin temperature, and heart rate. Moreover, RPE, thermal sensation and discomfort were higher during the simulated firefighting activity. Although finish time was similar, the last task of the activity was completed slower after pre-warming. Also, self-reported performance quality was lower after pre-warming than after starting thermoneutral. It was concluded that pre-warming reduced the speed during the last part of simulated firefighting activity and also reduced self-reported quality of performance. These findings show that it is important to carefully plan activities in the firehouse that may increase body temperature, as these may impair subsequent performance.

Collectively, these chapters indicate that several thermal(psycho)physiological signals are relevant for the selection and modulation of pacing strategies during exercise in the heat, both at the start and during exercise. It appears that skin temperature and expectations about the thermal load during an upcoming exercise bout are relevant for the selection of starting exercise intensity. Body heat content, core temperature and thermal perceptions seem to be relevant for modification of the intensity during exercise. The influence of these signals on the self-selected exercise intensity depends on environmental conditions and the duration of exercise.