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Self-paced cycling performance and recovery under a hot and highly humid environment after cooling

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Aim. This study investigated the effects of pre- and post-cooling on self-paced time-trial cycling performance and recovery of cyclists exercising under a hot and highly humid environment (29.92 °C-78.52% RH).

Methods. Ten male cyclists performed a self-paced 20-min time trial test (TT_{20}) on a cyclo-ergometer while being cooled by a cooling vest and a refrigerating headband during the warm-up and the recovery period. Heart rate, power output, perceived exertion, thermal comfort, skin and rectal temperatures were recorded.

Results. Compared to control condition (222.78±47 W), a significant increase ($P<0.05$) in the mean power output during the TT_{20} (239.07±45 W; +7.31%) was recorded with a significant ($P<0.05$) decrease in skin temperature without affecting perceived exertion, heart rate, or rectal temperature at the end of the TT_{20}. However, pace changes occurred independently of skin or rectal temperatures variations but a significant difference ($P<0.05$) in the body's heat storage was observed between both conditions. This result suggests that a central programmer using body's heat storage as an input may influence self-paced time-trial performance. During the recovery period, post-cooling significantly decreased heart rate, skin and rectal temperatures, and improved significantly ($P<0.05$) thermal comfort.

Conclusion. Therefore, in hot and humid environments, wearing a cooling vest and a refrigerating headband during warm-up improves self-paced performance, and appears to be an effective mean of reaching skin rest temperatures more rapidly during recovery.

KEY WORDS: Humidity - Athletic performance - Body temperature regulation.

The concept that hot and humid environments have a detrimental effect on performance is generally accepted [1-3] and has prompted many studies on thermoregulation. These temperature issues were especially apparent approaching the Olympic Games in Atlanta in 1996,[4, 5] in Athens in 2004 [6] and, more recently, in Beijing in 2008.[7, 8] Studies, aiming at increasing human performance at high ambient temperature, have examined the effects of body cooling before exercise (pre-cooling) using leg or whole body water immersion,[4, 5, 9] cold-air exposure [10] or cooling garments.[11, 12] In general, starting a competition with a cooler body would appear to enable athletes to increase their heat storage and endurance performance level before reaching a limiting core temperature. This result may be explained by a significant decrease in skin temperature,[13] in central temperature,[14] or in both.[4, 5, 10, 15] A decrease in body temperature is usually associated with an enhancement of endurance performance by increasing the distance covered in a fixed time,[4] the time before exhaustion,[10, 15] or the extent of power output developed.[14, 16] Precooling at controlled exercise intensity decreases heart rate[2, 4, 7, 10, 15] and perceived exertion[4], while increasing thermal comfort[17].

Most of the exercise protocols used in previously published studies fixed the speed or power output developed by the athletes, and a few studies

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examined the influence of pre-cooling on self-selected-intensity exercises. Moreover, the warm-up protocol prior to self-paced exercise was not explained,[4, 5] not controlled,[7] or only partially controlled.[8] St Clair Gibson and Noakes [18] postulated that pacing might be controlled by a "central governor" with feedback and feedforward mechanisms that use information about thermal load, exercise intensity, energy stores and fluid balance. Because the use of a precooling manoeuvre during warm-up could provide "misinformation" to the central governor, as recently reported by neck cooling studies,[19, 20] the ability to select an appropriate pace may be altered, and this could affect the regulation of effort.

Excessive rounds of intense training and competitions, particularly with short recovery time, can impose great physiological and psychological constraints that are detrimental to performance. For this reason, different body-cooling methods initiated after or between exercises (postcooling) have been investigated with the aim of increasing rate and extent of recovery in athletes.[21, 22] Postcooling has been found effective in hot environments as a recovery method where a decrease in central and/or peripheral temperatures is desired in order to return quickly to normothermia and/or to minimize aches, leg pains and muscle damages.[23] Nevertheless, although an increasing number of athletes use post-cooling during recovery, the effectiveness of this method is equivocal because most tests of cooling methods have not accurately controlled the exercise intensity, environmental conditions, or physiological and perceptual responses of the subjects [12, 22] or are mixed with others methods.[24]

Therefore, the aim of the present study was to test the effects on trained cyclists of a cooling method on physiological and perceptual responses during and a self-paced cycling exercise performed in a hot and extremely humid environment. Our first hypothesis was that pre-cooling during a standardised warm-up could influence the performance level and the pacing strategy of the athlete during a self-selected intensity exercise, by increasing the exercise intensity.

Our second hypothesis was that post-cooling during the recovery period could decrease the time required to attain normothermia, in spite of this hypothetical increase in intensity during the previous exercise.

Materials and methods

Study population

Ten trained male road-cyclists (mean±standard deviation; age: 21.36±1.80 years old, height: 178.90±4.30 cm, $\dot{V}O_2$max: 59.14±7.01 mL.min^{-1}.kg^{-1}, maximal aerobic power: 321.90±57.00 W, body mass: 71.63±4.32 kg, percentage of body fat: 14.98±1.57%, body mass index: 22.15±1.01, body surface area:[25] 1.9±0.08 m^2 with 6±2 years of competition experience volunteered to participate in this study. All subjects were involved in a regular physical training regimen. The subjects gave their written consent to participate in the investigation. The experiments complied with the Helsinki declaration (1983), and the protocol was approved by the local ethics committee. The subjects were asked to maintain their normal diet (avoiding caffeine, smoking in the previous 12-hours) and training during the study. Each subject was familiarised with the testing protocol and equipment, but was not informed about the expected study results. Each subject was tested at the same time of day, under two counter-balanced and randomised conditions: with combined pre- and postcooling or without any cooling method. Tests were carried out at one-week intervals.

Control conditions (without cooling method)

Each subject performed a standardised 20-min cycling warm-up during which the power output was accurately controlled (Table I). The warm-up comprised four incremental levels: level 1 consisting in 5 minutes at 50% of maximal aerobic power (MAP); level 2: 5 minutes at 66% of MAP; level 3: 5 minutes at 83% of MAP and level 4: 2 minutes at 100% of MAP. The MAP had been measured one week before the experiment during a maximal graded test carried out up to the point of exhaustion. A 3-min period of active recovery at 50% of MAP was then performed, followed by 5 minutes of passive recovery while sitting on the bicycle. This exercise bout corresponded to the exercise intensity of the warm-up usually performed on a home trainer by riders before time trial cycling competitions.[26]

Each subject used his own racing bicycle equipped with a power-output measuring device built into the hub of the rear wheel (PowerTap, Cycleops, Saris

TABLE I.—*Description of the experimental conditions and protocol timing.*

Warm-up					Recovery	TT20	Recovery	
5 min	5 min	5 min	2 min	3 min	10 min	20 min	0-15 min	15-30 min
Test protocol duration								
50% of MPA	66% of MPA	88% of MPA	100% of MPA	50% of MPA	Passive recovery	Maximal self-selected intensity	Passive recovery	
Cooling intervention					No cooling		Cooling intervention	No cooling
No cooling								

Cycling Group Inc., Madison, WI, USA) and mounted on a calibrated home trainer [27] (CatEye CS-1000, Cat Eye Co., Osaka, Japan). The participants were asked to develop their maximal power output during a 20-min time trial (TT_{20}). A 20-min time trial was chosen in order to determine the individual endurance capacity at a steady state of blood lactate.[28] During this test, the subject was invited to self-adjust the mechanical power output developed by using a pacing strategy. The power output, pedalling rate and heart rate displayed on the unit monitor were masked. The subject was only informed of the elapsed time. Each session (warm-up, break between the warm-up and the time trial, time trial and the 30-min recovery period) occurred in a climate controlled chamber where the temperature and humidity were accurately controlled (29.92±0.40 °C and 78.52±2.48% of relative humidity). In addition, during the TT_{20}, the subjects were cooled by an electric fan with a constant wind speed [29] (2.66 m/s), and they were wearing the same standard cycling apparels [30] with shorts and jersey both made of 100% polyester.

During the experiment, athlete's heart rates were continuously monitored by a heart-rate recorder (PowerTap, Cycleops, Saris Cycling Group Inc., Madison, WI, USA). Skin thermistors (YSI 409B Temperature Probe, YSI Inc.; Yellow Springs, USA and Digi-Sense Thermistor thermometer model 60010-70; Barnant Inc., Barrington, IL, USA) were attached under their cycling apparel to the midpoint of the right pectoralis major, and to exposed skin at the midpoint of the right triceps brachii lateral head, the right rectus femoris, and the right gastrocnemius lateral head. Skin temperature was recorded at the end of each level during the warm-up, every 2 min during the TT_{20}, and after 15 minutes and 30 minutes of recovery. Mean skin temperature (T_{skin}) was calculated on the basis of the Ramanathan [31] equation:

$$T_{skin} = 0.3\ T_{ch} + 0.3\ T_a + 0.2\ T_t + 0.2\ T_c,$$

where T_{ch} is the chest temperature, T_a is the arm temperature, T_t is the thigh temperature, and T_c is the calf temperature. In addition, rectal temperature (T_{rec}), (OMRON 1 temp, OMRON Co., Kyoto, Japan) was recorded at rest, at the end of the warm-up and the TT_{20}, and during recovery (15 minutes and 30 minutes after the TT_{20}). The calibrated rectal thermistor was inserted 10 cm past the anal sphincter. Since participants felt uncomfortable with a rectal probe inserted while cycling, the thermistor was removed after each measurement: 1) at rest; 2) at the end of warm-up; 3) at the end of the TT_{20}; 4) after 15 minutes of recovery; and 5) after 30 minutes of recovery.

The total body temperature (T_{body}) used in this study was calculated from skin and rectal temperature using the following equations:[31]

$$T_{body} = 0.79\ (T_{rec}) + 0.21\ (T_{skin})$$

Heat content was calculated using the following equation:

$$Q_c = T_{body} \times m \times 3.47$$

Where Q_c was the heat content, T_{body} was the body temperature in °C, m was body mass in kg and 3.47 was a constant measured in kJ.°C^{-1}.kg^{-1}.

Mean heat storage during the TT_{20} was calculated with the following equation:

$$\text{Mean } Q_s = (Q_{c,\ t1} - Q_{c,\ t2})/20$$

where Q_s is mean heat storage in kJ.min^{-1}, $Q_{c,\ t1}$ is heat content at the end of the warm-up and $Q_{c,t2}$ is the heat content at the end of the TT_{20} and 20 is the duration (in minutes) of the TT_{20}.

Perceived exertion (the RPE 6-20 of Borg [32]) and thermal comfort (the feeling scale of Hardy, and Rejeski [33] adapted for thermal comfort) were also recorded every 2 minutes during the TT_{20}, but also during the warm-up and after 15 minutes and 30 minutes of recovery. This feeling scale is a graduated scale with a range from -5 to +5: -5 corresponds to a very cold sensation and +5 to a very hot one. Zero corresponds to a neutral thermal sensation. During the entire experiment and in order to mimic the competition conditions, subjects could drink slightly cooled (14 °C) water *ad libitum*.

Cooling conditions (with pre-/postcooling)

The warm-up was performed under the same environmental conditions as the control conditions. However, this time, during the warm-up period, the 5 minutes of passive recovery before the TT_{20} and the recovery period (during the first 15 minutes immediately after the end of the TT_{20}), the subjects were equipped, over their standard cycling apparels, with cooling jersey with gel packs inserted-in (Ice-Shirt, Vtherm Inc., Roche Lez Beaupré, France) to cool the pectoralis, deltoids and scapulae (covering about 20% of the body surface area), and with a headband in which water-absorbent crystals were encapsulated (Coolmor Cooling Head Band, Roshgo Co Atlanta, GA, USA) to cool the forehead (covering about 3% of the body surface area). Before being worn, the headband was kept cool in 5 °C water, and the cooling vest was kept for 30 minutes at -18 °C inside an icebox. While being worn, both items delivered an 8 °C temperature to the skin through conduction.

Statistical analysis

Data were analysed as means (M)±standard deviations (SD). The data from the present study met statistical assumptions for use of parametric statistics (*i.e.*, homogeneity of variance and normality of the sample distribution), so a two-way repeated measures ANOVA (conditions x time) was used, followed by a Scheffé *post hoc* test (Statview, SAS Institute Inc., version 5). The possible changes in power output observed during pedalling, independent of P value, were investigated in relation to the within subject coefficient of variation (CV) for power output. These changes in power output within this zone were considered unimportant. By using conventional alpha (0.05) and beta (0.02) assumptions, we estimated that 10 subjects would provide sufficient power to find a meaningful difference in power output equal or greater than the CV, which was estimated as 5% based on a recent study.[30] This is equal to a change in power output of ~ 7 W/2 min. A regression analysis was also used to determine a possible link between the time and the power output developed during the TT_{20} test. A paired "t" test was used to compare the water intake and the rate of heat storage of both groups. Statistical significance was accepted at the $P<0.05$ level.

Results

Power output

The power output developed during the TT_{20} showed a significant condition effect ($P<0.01$) but no time effect ($P=0.46$) or interactions ($P=0.99$). As indicated in Figure 1, *post hoc* tests revealed that the power output developed in the cooling condition (mean values: 239.07±45 W) was significantly higher ($P<0.05$) than that in the control condition (mean values: 222.78±47 W). This difference represents a mean power output difference of 16.29 W (+7.31%) between the two conditions.

Pacing strategies

The participants maintained a pace throughout the first 18-min of the TT_{20} that varied by 1.55% and 1.64%, respectively in control and cooling conditions, which does not represent any significant difference. During this period, a correlation analysis between power output and skin temperature indicated a "U" shape second order polynomial significant correlations ($P<0.05$ and $P<0.01$, respectively in the cooling and control conditions). For the period between the 18th and the 20th minutes of the TT_{20}, the participants experienced the same end spurt pace of 12.37% and of 12% respectively in control and cooling conditions. These relationships suggest that pace changes were independent of the variations of skin temperature.

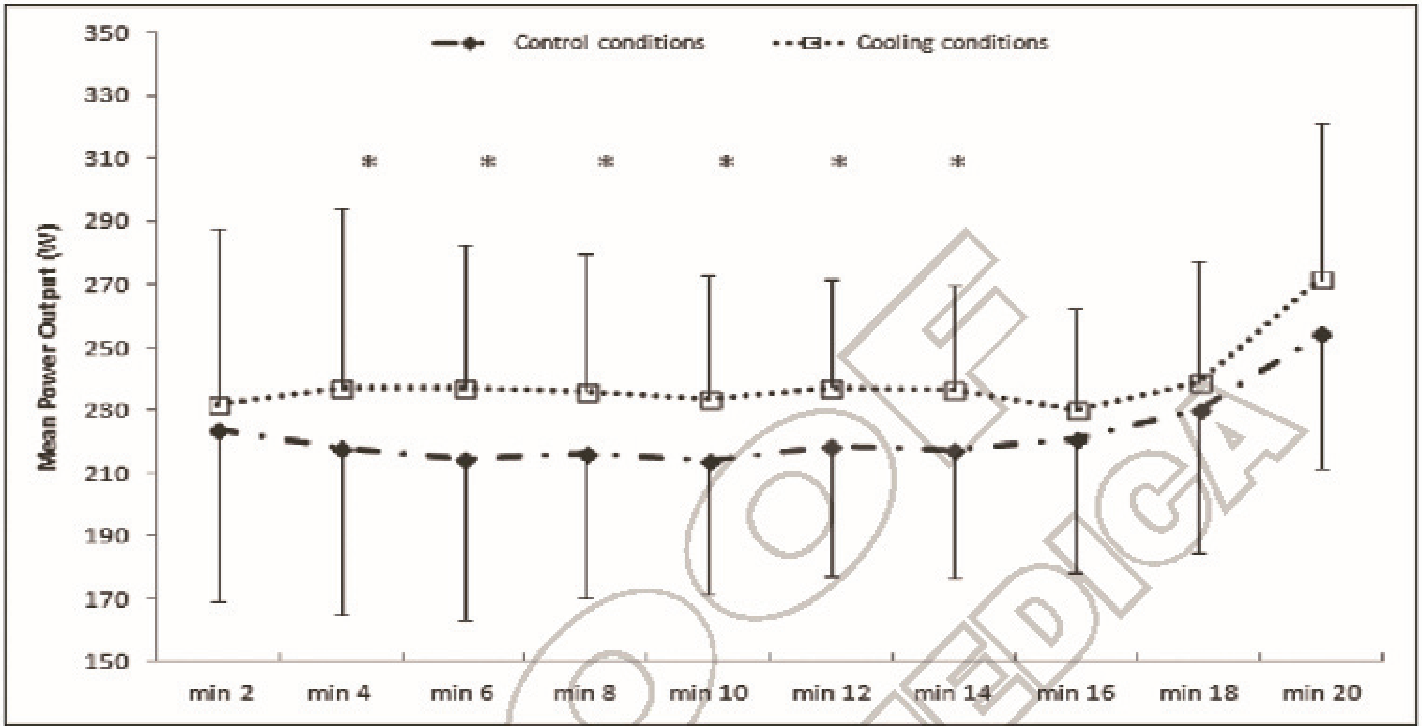

Figure 1.—Group mean response (± standard deviation, N.=10) for the power output during a 20-min time trial at self-selected intensity. * Significantly different (P<0.05) between both conditions.

Skin, rectal temperatures, heat storage and cooling rates

Skin temperature results showed a significant condition effect (P<0.01) and time effect (P<0.01), but no interactions (P=0.68). As indicated in Figure 2, *post hoc* tests revealed that the skin temperature measured in the cooling condition was significantly lower (P<0.05) than the control condition during the warm-up (mean values for the warm-up period: 35.12±0.92 °C *vs.* 35.76±0.49 °C), but also at minutes 2, 4, and 6 during the TT_{20} (mean values for the TT_{20} period: 35.91±0.63 °C *vs.* 36.21±0.39 °C) and after recovery (35.01±0.22 °C *vs.* 35.50±0.32 °C after 15 minutes of recovery and 34.80±0.23 °C *vs.* 35.30±0.30 °C after 30 minutes of recovery).

For the rectal temperature, significant condition effects (P<0.01) and time effects (P<0.01) were found. No significant interactions were observed (P=0.83). The rectal temperature was not significantly different between conditions at rest (P=0.82), at the end of the TT_{20} (P=0.56) or after 15 minutes of recovery (P=0.21) (Figure 3).

In the cooling condition compared to the control condition, *post hoc* tests revealed that the rectal temperature was significantly lower (P<0.05) at the end of the warm-up (37.67±0.46 °C *vs.* 37.96±0.32 °C) and after 30 minutes of recovery (P<0.01) (37.46±0.41 °C *vs.* 37.92±0.57 °C).

In addition, the amount of core temperature accumulated during the TT_{20} was significantly more important (P<0.05) during cooling condition (1.39±0.5 °C) compared with control condition (0.99±0.5 °C). The rate of heat storage confirms this result by indicating values significantly higher (P<0.05; t=2.37) in the cooling condition (-16.54±6.33 $kJ.min^{-1}$) compared to the control condition (-9.81±6.48 $kJ.min^{-1}$).

The cooling rate was also significantly higher (P<0.05) after the first 15-min of recovery (0.02±0.04 $°C.min^{-1}$ in the control condition *vs.* 0.05±0.02 $°C.min^{-1}$ in the cooling condition). There was no significant difference between cooling rates within the 15-to-30-min period (0.02±0.02 $°C.min^{-1}$ in the control condition *vs.* 0.03±0.02 $°C.min^{-1}$ in the cooling condition). Results for the overall recovery period of 30 minutes show a significantly higher (P<0.01) cooling rate (0.05±0.02 $°C.min^{-1}$) in the cooling con-

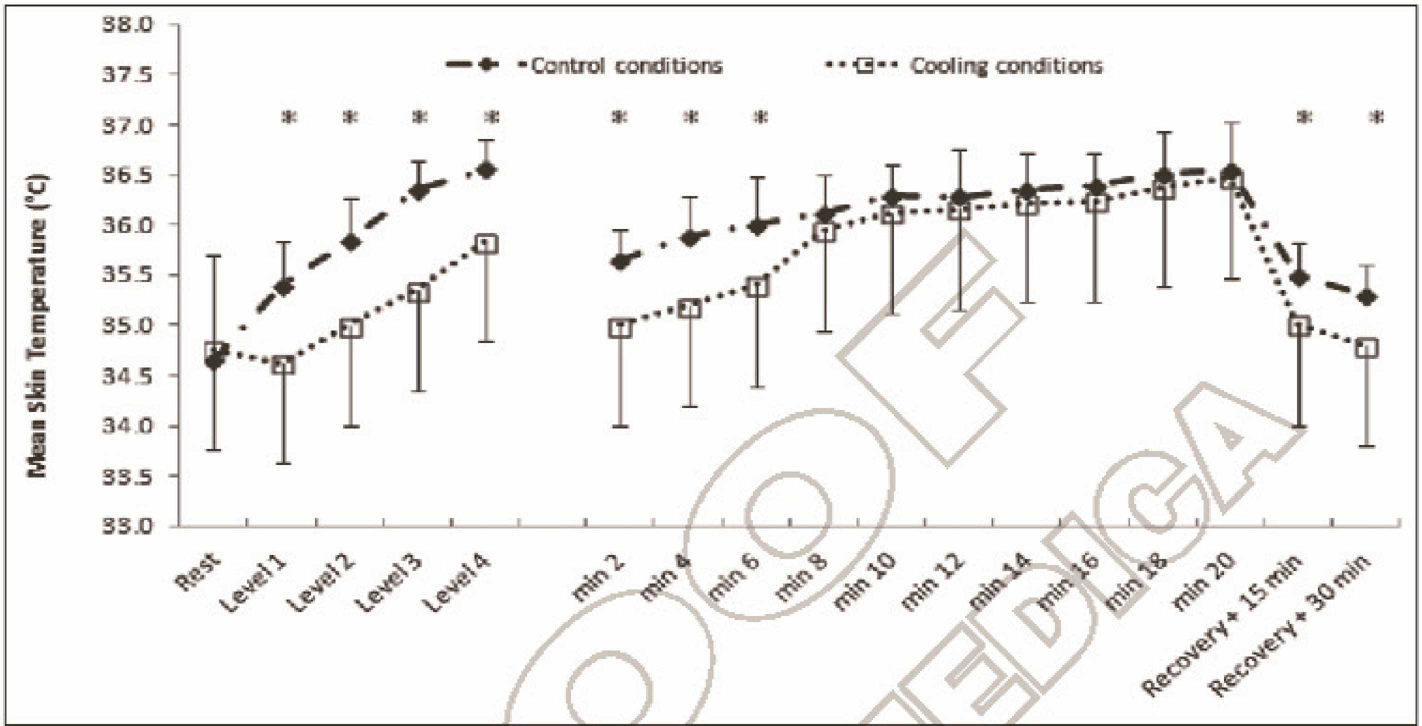

Figure 2.—Group mean response (± standard deviation, N.=10) for skin temperature during a standardised warm-up, a 20-min time trial at self-selected intensity and the recovery period. * Significantly different (P<0.05) between both conditions.

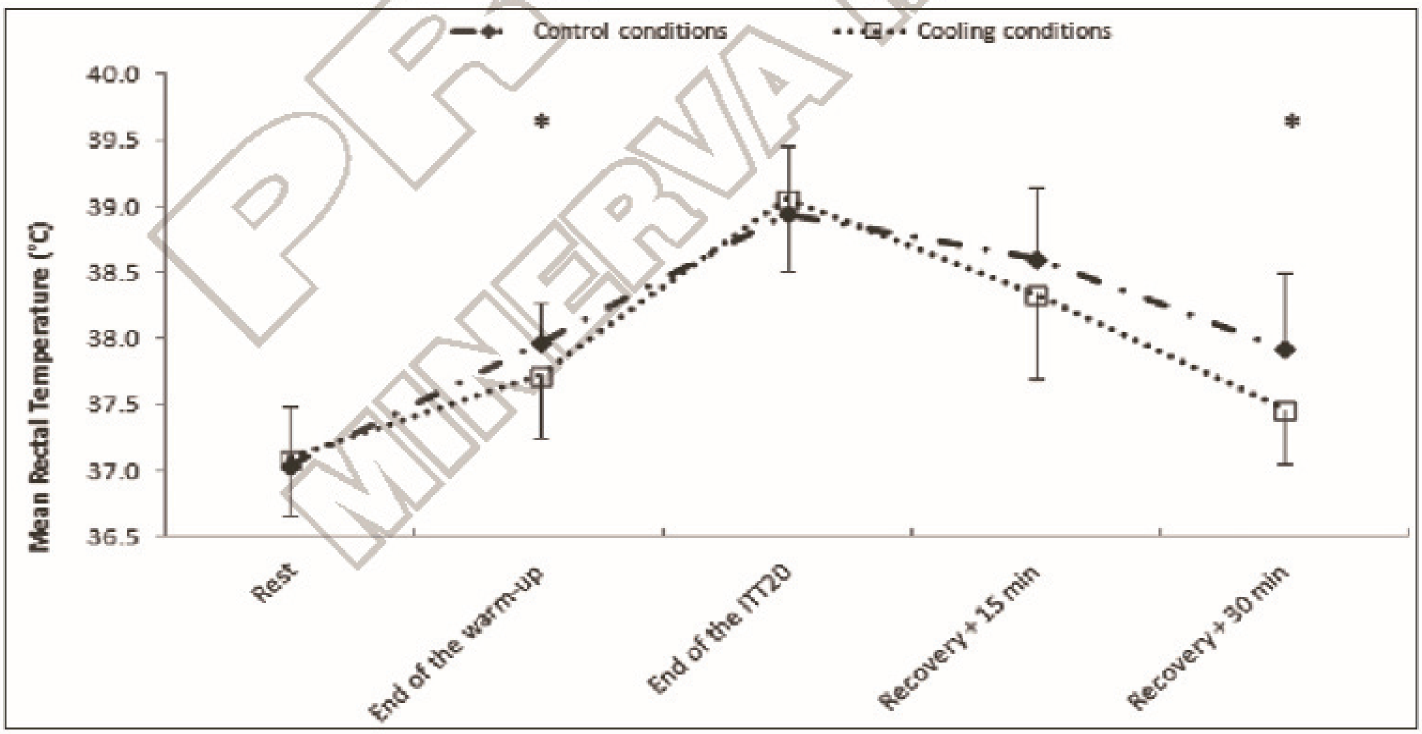

Figure 3.—Group mean response (± standard deviation, N.=10) for rectal temperature at rest, at the end of a standardised warm-up, of a 20-min time trial at self-selected intensity (TT_{20}), and during the recovery period and cooling rate during the recovery period. * Significantly different (P<0.05) between both conditions.

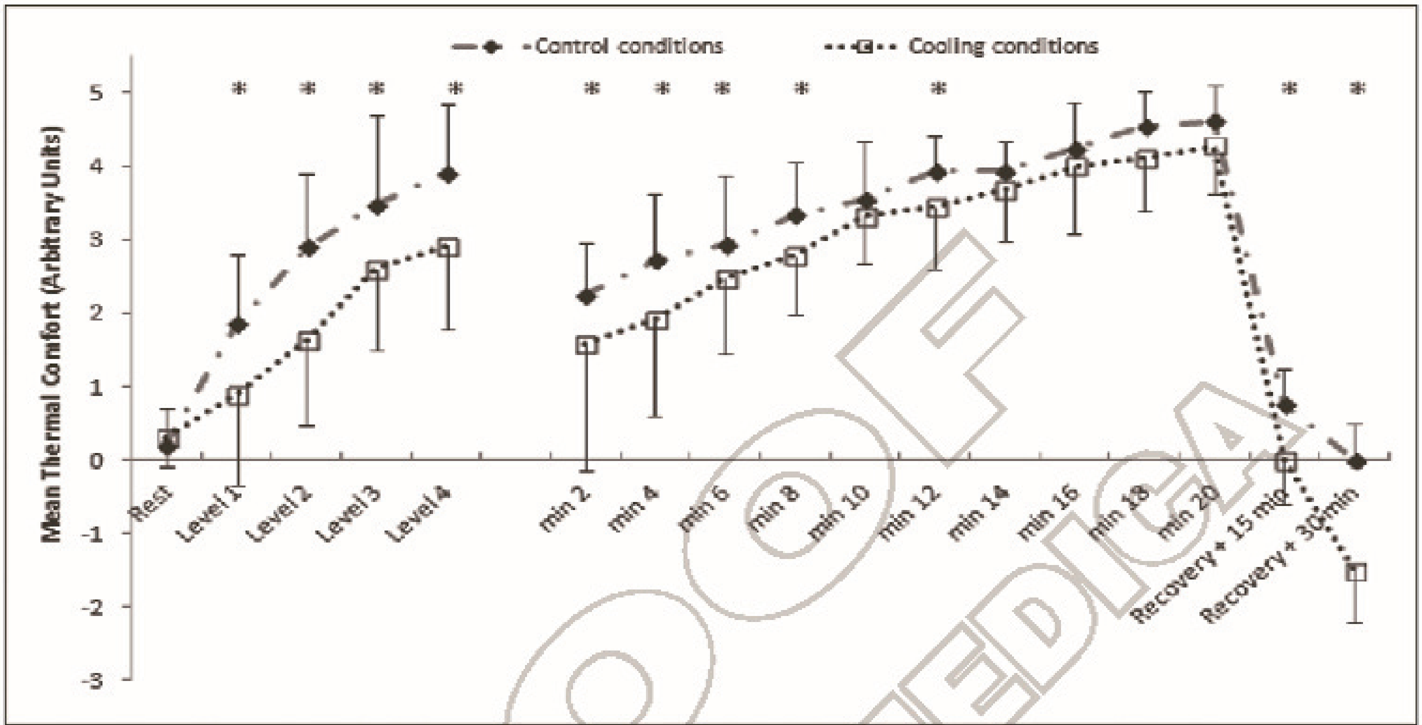

Figure 4.—Group mean response (± standard deviation, N.=10) for thermal comfort during a standardised warm-up, a 20-min time trial at self-selected intensity, and the recovery period. * Significantly different (P<0.05) between both conditions.

dition compared to the control condition (0.03±0.01 °C.min-1).

Perceptual responses

Perceived exertion showed a significant condition effect (P<0.01) and time effect (P<0.01), but no interactions (P=0.92). *Post hoc* tests revealed no significant differences in mean perceived exertion between control and cooling conditions during the TT_{20} (16.12±1.55 *vs.* 15.97±1.51), but a significantly lower RPE-score in the cooling condition at levels 2 and 3 of the warm-up (11.55±2.08 *vs.* 12.80±1.63 at level 2 and 13.15±2.16 *vs.* 14.30±2.05 at level 3).

Thermal comfort showed a significant condition effect (P<0.01) and time effect (P<0.01), but no interactions (P=0.94). As indicated in Figure 4, a significant difference (P<0.05) was observed between both conditions during the warm-up, at minutes 2, 4, 6, 8 and 12 during the TT_{20}, and during the entire recovery period (0.75±0.5 in the control condition *vs.* 0±0.6 with post-cooling after 15 minutes of recovery, and 0±0.5 in the control condition *vs.* -1.5±0.70 in the cooling condition after 30 minutes of recovery).

Heart rate

Heart rate showed a significant group effect (P<0.05) and time effect (P<0.01), but no interactions (P=0.99). No significant difference was observed during warm-up (139.38±36.45 bpm in the cooling group *vs.* 140.25±42.10 bpm) and TT_{20} (176.32±6.54 bpm after precooling *vs.* 179.56±6.95 bpm), but a significant difference was found between both conditions after 15 min (110.01±8.18 bpm in the control condition *vs.* 97.05±15.13 bpm with postcooling) and 30 min of recovery (85.16±12.49 bpm in the control condition *vs.* 75.13±2.08 bpm with postcooling).

Water consumption

The water intake by the subjects was not significantly different (P=0.65) between the two conditions (1002±626 mL in the control condition *vs.* 1061±647 mL in the cooling condition).

Discussion

This study aimed at testing two hypothesis: that pre-cooling could influence the performance and the pacing strategy during a self-selected intensity exercise; and that the post-cooling method used in this study would be efficient on recovery. The most important finding of the present study is that pre-cooling increases significantly the mean power output developed during a self-paced cycling exercise, but this increase occurred independently of the variations of the skin and rectal temperatures. Indeed, the pacing strategies revealed small variations of 1.64% in the cooling condition and 1.55% in the control condition for the 18 first minutes of exertion, and a CV of the pacing for the last 2-min of exercise of 12% in the cooling conditions and of 12.37% in the control conditions. Compared to Ely *et al.*[34] and to Byrne *et al.*[35] studies, the "low" rectal temperatures (*i.e.* <40 °C) recorded at the end of TT_{20} (39.06±0.50 °C and 38.94±0.50 °C in the cooling and control conditions, respectively), do not approach any hypothetical critical core temperature that could reduce metabolic heat production and protect physiological integrity at times of high endogenous and/or exogenous heat load.[2, 18, 36] Therefore, other physiological or psychological inputs appear to influence mean power output and pacing, such as the body's heat storage.

Indeed, the significant difference of mean rate of heat storage found during TT_{20} under cooling condition underpins this hypothesis that was previously reported by Tucker.[37] These authors had observed that heat storage was a sensed variable which regulated the exercise intensity when the endpoint was unknown before the exercise bout began. Our results suggest that this variable may also be influent in self-paced exercise when the endpoint is fixed. The perceived exertion values recorded during the experiment may confirm this hypothesis. During the warm-up when the power output was fixed, the values for perceived exertion and thermal comfort were significantly higher under the control conditions. Perhaps for this reason, the subjects immediately started the TT_{20} at a moderate self-selected intensity (mean power output 222.78±47 W) in order to reach a peak heart-rate value at the end of TT_{20}. Under the cooling conditions, the subjects reported lower values of perceived exertion and thermal comfort at the end of the warm-up. They then self-selected and maintained higher exercise intensities for 20 minutes (mean power output 239.07±45 W). This mechanism was reported by Ulmer,[38] who suggested that a central "programmer", probably working at a subconscious level, calculated the time necessary to complete an activity. The author included this in a calculation of the power output required to complete the task while maintaining homoeostasis (*i.e.*, a reserve of body heat storage in the present study) in all the bodily systems.

The significant increase ($P<0.05$) of 16.29 W, or 7.31%, observed in the present study is in line with that reported previously,[5, 7] where power output increases of, respectively 6.04%, and 11.23%, were recorded after precooling. However, our differences are less pronounced than those that reported[16] gains in power output of 17.06%. This discrepancy may be explained by the fact that the subjects in this study used different precooling methods (an ice-vest and cold air), were tested during a longer cycling exercise (35 minutes). Nevertheless, our differences are more pronounced than those reported by Arngrïmsson,[6] who observed a gain of 1.15% in a 5-km-running test. In addition, the extreme relative humidity of the environment tested in this present study (78.52% RH) might also explain this discrepancy (~ -10%).[39] It is actually known[39] that such a high relative humidity decreased the efficiency of loss of heat through sweating, or disabled this heat loss.

Other factors may also partly explain the improvements in power output after pre-cooling. Indeed, heart rates were not significantly different under both conditions before and during the TT_{20} even if the subjects developed a significantly higher power output when they were cooled. In addition, no significant difference in perceived exertion was observed between either TT_{20} performances. Therefore, the rate of heat storage and dissipation mechanisms may compete with active muscle for blood flow and, without precooling, this increased blood flow to the skin for heat dissipation may result in lower power output for similar cardiovascular and perceived exertion responses.[40]

During the recovery period, a significant decrease in heart rate was observed. This result is in line with the findings of Mourot,[41] who reported that cooling resulted in a lower heart rate. The authors reported that cooling the peripheral tissues induced a vasoconstriction response that reduced blood flow to the skin and peripheral tissues. Peripheral vasoconstriction could increase peripheral resistance, resulting in a rise in arterial pressure and a subsequent baroreceptor response that decreased the heart rate. This vasoconstriction could also result in an increase of the central venous pressure and stroke volume that would decrease the heart rate.

Postcooling significantly improved the thermal comfort and decreased the skin and rectal temperatures, indicating a benefit for thermoregulation and a faster recovery process. The cooling rates recorded after 30 min of recovery (0.05±0.02 °C.min^{-1}) are superior to those found by Brade,[12] who reported 0.04±0.01 °C/min values in athletes wearing a gel jacket. This result suggests that wearing a cooling jersey and headband immediately after exercise is an effective and simple method for significantly decreasing the time required for attaining normothermia.

Conclusions

The results of the present study suggest that, in a hot and extreme humid environment, wearing a cooling jersey and headband during a standardised warm-up increases the performance of cyclists, allowing them to increase their mean power output during a self-selected 20-min time trial. The significant increase in power output is associated with a decrease in skin temperature, thermal comfort rates, without affecting perceived exertion, rectal temperature or heart rate. However, pace changes occurred independently of variations of the skin and rectal temperatures, but the rate of heat storage may influence self-paced time-trial performance without reaching a limiting core temperature. After the exercise, postcooling significantly decreased the heart rate and the skin and rectal temperature of subjects, suggesting that the use of a cooling jersey and headband is a simple method for fast re-establishing normothermia under hot and extreme humid conditions.

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