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Title: Effects Of A Head-Cooling Cap On 5-Km Running Performance In The Heat

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ABSTRACT

Cooling the head region during exercise can enhance running performance, but this observation is limited to intermittent cooling. This study investigated the effects of continuous head cooling on 5-km running time-trial (TT) performance in hot conditions. Six male and four female triathletes completed two experimental sessions consisting of a two 10-minute runs at 50% and 70% $\dot{V}O_{2max}$ followed by a 5-km TT in the heat (32.0±0.3 °C, 50.1±1.2% RH). In a randomized crossover design, either an ice-filled cooling cap or no cooling cap was provided prior to the 10-minute run at 70% $\dot{V}O_{2max}$. Performance time, rectal, forehead and mean skin temperature, RPE, thermal comfort, fluid loss, blood lactate and heart rate were recorded. Performance time was faster with a cooling cap (1175±80 s) compared to no cooling cap (1189±76 s, $P = 0.034$; $d = 0.18$). The cooling cap reduced forehead temperature ($P < 0.001$) and improved thermal comfort ($P = 0.004$) but had no effect on any other variable ($P > 0.05$). Continuously cooling the head with an ice-filled cap enhanced 5-km TT performance in the heat. Participants reported an improved thermal comfort with no change in core temperature. Continuously cooling the head may be a practical strategy to enhance running performance in hot conditions.

KEY WORDS: cooling; heat stress; thermoregulation; thermal comfort; running.

INTRODUCTION

Environmental heat stress has been consistently demonstrated to attenuate endurance exercise performance (27, 38). Subsequently, evidence-based practical strategies that alleviate increases in body temperature, reduce the risk of heat illness and improve athletic performance are of interest. Cooling regions of the body has been the subject of several reviews, two of which examined the effects of cooling the body during exercise and suggested that "per-cooling", where the body is cooled during exercise, can augment endurance performance in the heat (4, 40). To date, research on per-cooling has focused on the effect of torso cooling using an ice vest (13), the intermittent ingestion of cold fluid (24, 30), menthol mouth rinse (34), palm cooling (16) and neck cooling using a cooling collar (21, 39, 41).

In a recent review, Stevens et al. (33) highlighted that per-cooling strategies typically enhance exercise performance in the heat by a combination of central nervous system (e.g. reduced activity of neurotransmitters and changes in skeletal muscle activation), cardiovascular (e.g. decreased heart rate) and psychophysiological mechanisms (e.g. improved thermal comfort and reduced rating of perceived exertion). However, a reduction in core temperature is uncommon in per-cooling investigations, although a meta-analysis indicates it frequently takes place in pre-cooling studies (4). In per-cooling studies, cooling the head is worthy of investigation, as the head, face and neck are areas of high alliesthesial thermosensitivity (11). Continuous facial fanning combined with intermittent water spraying has been shown to increase cycling time to exhaustion (1), whilst spraying the face at regular intervals during a 5-km run has been revealed to enhance running performance (32). In addition, Walters et al. (42) recently highlighted that intermittently cooling the head improved the peak power output during a maximal graded exercise test on a cycle ergometer. However, many of these per-cooling strategies have limitations for their use in a competitive environment. Indeed, Tyler et al. (40) stated that per-cooling methods can have issues concerning practicality such as skin irritation, sporting regulations and excess weight, and these issues may be responsible for the relatively limited interest in this area to date.

Despite the known ergogenic benefit of cooling the head as per-cooling strategies, to our knowledge, no study has investigated the effect of continuously cooling the head during exercise on subsequent running performance. Therefore, the purpose of this study was to determine the effect of wearing an ice-filled cooling cap on 5-km running performance in moderately hot and humid conditions in male and female endurance trained athletes.

METHODS

Participants

Ten non-heat acclimatized, male (n = 6; 24±3 y; 1.81±0.07 m; 76±8 kg; 63±5 mL·kg^{-1}·min^{-1}) and female (n = 4; 25±4 y; 1.73±0.09 m; 58±4 kg; 59±4 mL·kg^{-1}·min^{-1}) endurance trained triathletes were recruited from local triathlon clubs by sending the information to the coaches and then contacting the participants by email. The sample was selected by convenience to participate in this cross-sectional study. Participants performed 5-15 hours of endurance exercise (running, cycling, swimming) per week, of which at least 2 hours was running exercise. Confounding variables of caffeine, generic supplementation, prior thermal, hypoxic and hyperbaric exposures were all controlled in line with previous work in the field (36). After the experimental procedure, aims and potential risks were explained, all participants provided informed written consent. The study was approved by the University of Chichester Research Ethics Committee with procedures and protocols conforming to the 2013 Declaration of Helsinki and the ethical standards of the International Journal of Exercise Science (25).

Protocol

Participants visited the laboratory at the same time of day on 3 occasions, with all testing sessions seperated by a ≥48 hours. Participants arrived in a rested and fully hydrated state, a minimum of 3 hours post-prandial and having avoided strenuous exercise and caffeine consumption in the 48 hours preceding a test session. Adherence to these criteria were confirmed verbally and urine osmolality was measured using a portable refractive index osmometer (Osmocheck, Vitech Scientific, Horsham, UK). Adequate hydration was defined as <700 mosmol/kgH_2O (29). During the first session, participants completed: (1) a submaximal incremental running test and; (2) an incremental running test to volitional exhaustion, on a motorized treadmill (Ergo ELG 70, Woodway, Weil and Rhein, Germany) in ambient conditions (19.0 °C) for the calculation of submaximal running speeds and maximal oxygen uptake ($\dot{V}O_{2max}$) respectively. All subsequent tests were conducted on a motorized treadmill (Pulsar, H/P/ Cosmos Sports and Medical GmbH, Germany) in the heat (32.0 ± 0.3 °C, 50.1 ± 1.2% relative humidity) beginning with a familiarization of the 5-km time-trial run in an environmental chamber (TIS Services UK, Medstead, UK). Sessions 2 and 3 involved participants completing a 10 minute submaximal run followed by a 5-km time-trial run in the heat under two experimental conditions in a counterbalanced order: (1) an experimental condition in which participants wore a cooling cap for the 10 minute submaximal and 5-km time-trial and; (2) a control condition in which participants wore no cap. The cooling cap is a commercially available product (ICED Cap, Norcross, USA) made of polyester with an adjustable pocket that was filled with 305 ± 10 g of ice. Before the head cooling trials, the ice was frozen for 24–72 h at -18 °C and was then left in a portable cooler for 20 minutes before application. Participants were informed that it was being investigated whether a cooling cap helped (due to cooling) or hindered (due to weight) running performance.

The submaximal running protocol began at 9 $km \cdot h^{-1}$ for 5 minutes with subsequent stages increasing to 11 and 13 $km \cdot h^{-1}$. Between stages, participants rested on the treadmill for 30 s. Expired gas samples were collected in the final minute of each exercise stage using the Douglas bag technique. Linear regression (ordinary least squares) was used to describe the relationship between $\dot{V}O_2$ and submaximal running speed for all participants.

Following the submaximal incremental running test, $\dot{V}O_{2max}$ was determined. The test commenced at 11 $km \cdot h^{-1}$ for 1 minute and subsequently increased by 1 $km \cdot h^{-1}$ each minute until volitional exhaustion. The treadmill was set to a 1% gradient to simulate outdoor running (18). Expired gas samples were collected for ≥4 minutes prior to participants reaching volitional exhaustion, with the final Douglas bag collection only being analyzed when expired volume and collection time was greater than 65 L and 30 s, respectively. Expired fractions of O_2 and CO_2 were determined using a gas analyzer (Series 1400, Servomex, Crowborough, UK), calibrated using known gases (Air Liquide, West Bromwich, UK), and expired volumes measured using a dry gas meter (Harvard Apparatus Ltd, Edenbridge, UK). Oxygen uptake was calculated by means of standard

Geppert-Zuntz-Haldane transformation equations. For all participants, $\dot{V}O_{2max}$ was confirmed when the following criteria were met; 1) respiratory exchange ratio ≥ 1.15, 2) plateau in $\dot{V}O_2$ of < 2.1 ml $\cdot$kg^{-1} $\cdot$min^{-1} between the last two gas collections; and 3) an RPE ≥ 18 (15).

Sessions two and three began with participants recording their nude body mass (Seca Lta., Birmingham, UK). Subsequently, a rectal thermometer (Edale Instruments Ltd, Cambridge, UK) was self-inserted $\approx$10 cm past the anal sphincter to measure core temperature, and a heart rate monitor (Polar RS400, Polar Electro UK Ltd, Warwick, UK) recorded heart rate. Core temperature and heart rate were measured every minute of the submaximal run and every kilometer of the 5-km time-trial run. Skin thermistors (Edale Instruments Ltd, Cambridge, UK) were attached to the right-hand side of the participant's upper chest, mid humerus and mid-thigh, with a further thermistor being placed on the participant's nasal brow, for the measurement of forehead temperature (10). Skin temperature was recorded continuously using a digital thermometer (Edale Instruments Ltd, Cambridge, UK) and reported every minute and kilometer of the submaximal and time-trial run respectively. Mean skin temperature (T_{sk}) was calculated using the formula of Roberts et al. (28):

$$T_{sk} = 0.43 * T_1 + 0.25 * T_2 + 0.32 * T_3$$

where T_1, T_2, and T_3 are chest, bicep and thigh temperature. Rating of perceived exertion (RPE) was measured on a 6-20 point Borg scale (5), whilst whole body thermal comfort was recorded using a modified 10-point categorical scale where 1 = "extremely cold", 5 = "comfortable", and 10 = "extremely hot" (2). Thermal comfort and RPE were recorded at minute 5 and 10 of the submaximal run and every kilometre of the time-trial run. . Blood samples for analysis of plasma lactate (2300 STAT Plus™ analyser, YSI Life Sciences, Yellow Springs, USA) were taken using finger-prick method immediately post the 10 minute submaximal run. Sweat losses were determined by the change in nude body mass pre to post exercise. Sweat volume and mass were considered equal (i.e. 1 mL = 1 g) and were expressed as an absolute volume (L). Participants weighed themselves nude before and within 5 minutes following the completion of exercise to the nearest 0.1 kg.

The relationship between running speed and oxygen uptake (as a percentage of $\dot{V}O_{2max}$) was utilized to determine the treadmill speed at 50 and 70% of participants $\dot{V}O_{2max}$. Upon entering the chamber, participants completed a 10 minute warm up at 50% $\dot{V}O_{2max}$ followed by a 10 minute submaximal run at 70% $\dot{V}O_{2max}$ to permit the collection of metabolic data (data not published). A three-min rest period was provided between the warm up and the submaximal run, where participants were assisted in fitting the cooling cap to their head for one of the experimental trials.

The start speed for the 5-km time-trial was equal to the average speed maintained during the participant's recent (<3 months) personal best performance time. This running speed was maintained for the first 500 m and thereafter, could be increased or decreased at the request of the participant. It is acknowledge that this approach reduces the ecological validity of the performance test. However, since participants were blinded to the treadmill speed throughout the time-trial, a decision to fix the initial start speed was based on a desire to avoid the negative consequences that an initial start speed that was either too fast or too slow would have over a relatively short duration time-trials. Participants were provided with water *ad libitum* and received no physiological or verbal feedback during the time-trial, although they were informed of the distance covered. Every kilometre participants were reminded of their ability to change the treadmill speed should they wish, but were not told of their 5-km performance times until the study was completed. The cooling cap was refilled with ice (305 ± 10 g) immediately prior to the 5-km time-trial. No blood or expired gas samples were taken during the time-trial to avoid interference with the performance. Following the time-trial participants dried off and recorded their nude body mass.

Statistical Analysis

All statistical analyses were completed on SPSS v.23 (SPSS Inc, Chicago, IL). Overall 5-km performance time, blood plasma lactate concentration, and fluid loss were analyzed using a paired samples t-test. Differences between heart rate, perceptual measures, rectal, skin and forehead temperature were analyzed using a two-way (condition vs. time) analysis of variance with repeated measures. Where appropriate post-hoc t-tests were used. Mauchley's Test of Sphericity was conducted to test for homogeneity of data and where violations were present Greenhouse-Geisser adjustments were made. To determine the TT effect size, Cohen's d was calculated (9). All data are reported as mean ± SD and statistical significance was set $P \leq 0.05$.

RESULTS

A cooling cap reduced 5-km completion time (Cooling Cap: 1175 ± 80 s, No Cap 1189 ± 76 s, $P = 0.034$), with a mean group reduction of 1.2 ± 1.4% (range -1.2 to 3.0%) and 8 participants showing a decrease (Fig. 1). Post hoc effect size calculations indicate a 0.18 (small) effect size.

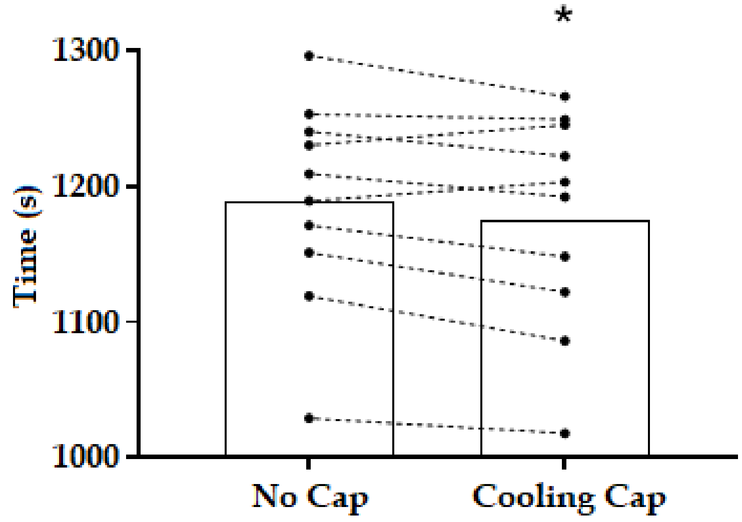

Figure 1. Time taken to complete the 5-km time-trial. Columns show group mean. Dashed lines show the individual responses. * completion time was reduced with a cooling cap ($P < 0.05$). Eight participants had faster times with the cooling cap.

Forehead temperature throughout the submaximal and time-trial run (Fig. 2) demonstrated a time ($P = 0.020$), condition ($P < 0.001$) and interaction effects ($P = 0.005$). Similarly, there was a main effect of time on heart rate ($P < 0.001$), rectal ($P < 0.001$) and skin temperature ($P = 0.009$). However, there were no differences between the conditions for heart rate ($P = 0.879$) rectal ($P = 0.516$) or skin temperature ($P = 0.889$). Mean heart rate, rectal and skin temperature are presented in Table 1.

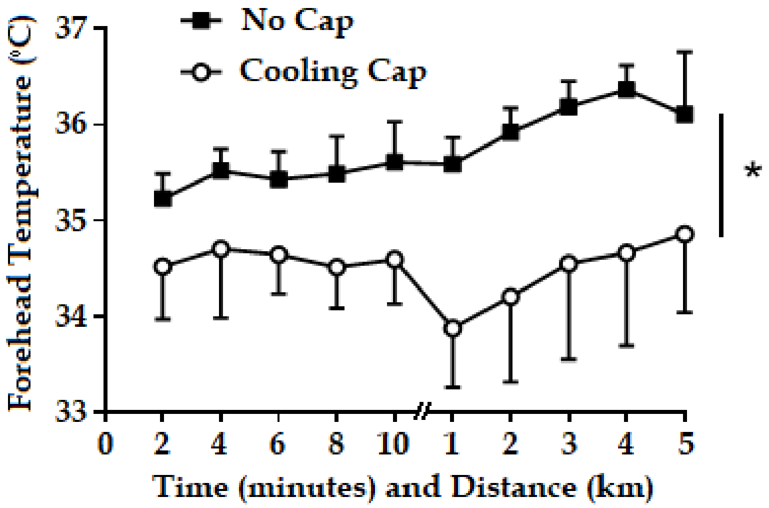

Figure 2. Forehead temperature during the 10 minute submaximal run at 70% $\dot{V}O_{2max}$ and 5-km time-trial. Data are mean ± SD. * denotes significant difference at all time-points ($P < 0.05$).

Table 1. A comparison of heart rate, core and skin temperature during the 10 minute submaximal and 5-km time-trial run between the conditions (Cooling Cap vs. No Cap). There were no differences between the conditions for heart rate (P = 0.879) rectal (P = 0.516) or skin temperature (P = 0.889).

Time/Distance	Heart rate (beats·min^{-1})		Core temperature (°C)		Skin temperature (°C)	
	Cooling Cap	No Cap	Cooling Cap	No Cap	Cooling Cap	No Cap
2 min	136±7	140±10	37.48±0.24	37.50±0.22	34.19±0.41	34.11±0.39
4 min	146±10	146±10	37.60±0.28	37.66±0.24	34.34±0.40	34.31±0.43
6 min	152±10	151±9	37.74±0.31	37.76±0.22	34.46±0.53	34.45±0.57
8 min	152±12	150±10	37.85±0.27	37.87±0.25	34.43±0.53	34.48±0.48
10 min	156±12	155±12	37.93±0.29	37.95±0.29	34.52±0.49	34.57±0.57
1 km	173±9	172±7	38.20±0.32	38.12±0.28	34.43±0.39	34.41±0.37
2 km	178±6	179±6	38.50±0.29	38.44±0.23	34.55±0.36	34.59±0.30
3 km	181±7	180±6	38.81±0.29	38.69±0.23	34.62±0.46	34.66±0.37
4 km	183±6	181±6	39.11±0.29	39.00±0.19	34.73±0.37	34.79±0.41
5 km	185±5	184±5	39.33±0.29	39.22±0.20	34.86±0.41	34.87±0.41

Thermal comfort (Fig. 3) demonstrated time (P < 0.001) and condition effects (P = 0.004) with between condition effects equating to 11% (P = 0.010), 13% (P = 0.004), 8% (P = 0.024) and 6% (P = 0.015) at 5 min, 2 km, 3 km and 4 km respectively, although there was no interaction effect (P = 0.259). RPE also demonstrated time effects (P < 0.001) although there was no condition (P = 0.163) or interaction effect (P = 0.172). A difference between the conditions was observed for RPE at 1 km (Cooling Cap: 14.1 ± 1.5, No Cap: 15.1 ± 1.5, P = 0.008).

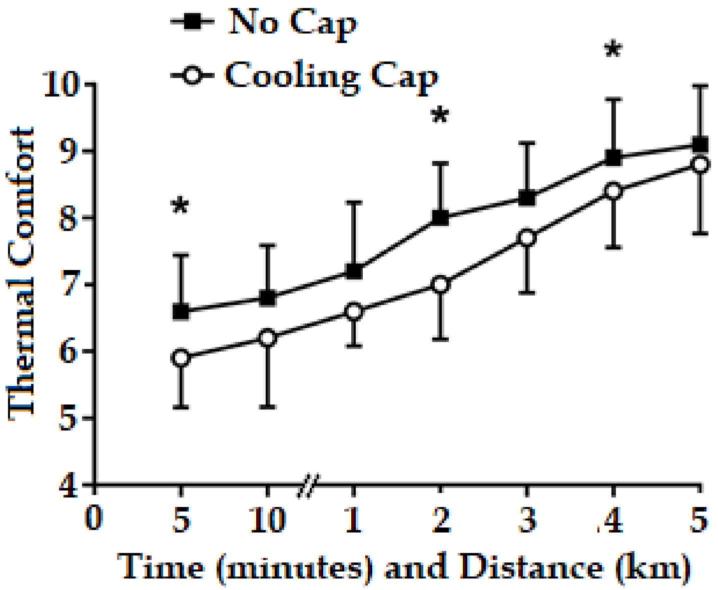

Figure 3. Thermal comfort during the 10 minute submaximal at 70% $\dot{V}O_{2max}$ and 5-km time-trial. Data are mean ± SD. * denotes P < 0.05 vs. no cap.

During the 10 minute submaximal run, there was no difference observed between the conditions for sweat loss (Cooling Cap: 1.26 ± 0.54, No Cap: 1.21 ± 0.38 L, $P = 0.767$) or blood lactate (Cooling Cap: 1.42 ± 0.58, No Cap: 1.49 ± 0.55 $mmol \cdot L^{-1}$, $P = 0.402$).

DISCUSSION

This is the first study to observe that continuously cooling the head region with an ice-filled cap enhanced time-trial running performance by 1.2% in trained runners. A performance improvement of 1.2% may seem small, however, this 14 s reduction in 5-km time is the equivalent of a 58 m enhancement at the average speed in the cooling cap condition. The magnitude of this change is comparable to the effects of other practises routinely adopted by endurance runners to improve performance, such as altitude (35) and strength (3) training, and the incorporation of high intensity warm-up regimens (17).

Hopkins (14) proposed that the "smallest important change" for elite athletes competing in running races between 3-10 km is ≈0.3%. Although the 1.2% performance improvement in the current study is higher than this value, it is lower than the 5-7% enhancement following continuous neck cooling (21, 39). However, it is feasible that a long duration pre-load of 75 minutes of running at 60% of $\dot{V}O_{2max}$ could have enhanced performance changes during the subsequent 15 minute time-trial. Indeed, in a two-part experiment using the same cooling collar Tyler et al. (41) observed that 15 minute time-trial performance was improved by 5.1% following a 75 minute pre-load, but when the same participants performed an unloaded 15 minute time-trial, performance improved by 1.9% in comparison to running with no cooling collar. More recently, studies have shown that facial water spraying (32) and menthol mouth rinse (34) enhanced 5-km time-trial performance by 2.4 and 2.7% respectively. Despite these 5-km performance improvements being greater than the current study, participants took an average of 24.6 ± 3.3 minutes with facial water spraying (32) and 25.3 ± 3.5 minutes using menthol mouth rinse (34) to complete the 5-km time-trials. In contrast, participants in the current study took just 19.6 ± 1.3 minutes with a cooling cap to complete the 5-km time-trial. It is suggested that performance improvements with the aid of "cooling" would typically be smaller for higher ability participants due to increased sweating, a slower rise in skin temperature and a smaller change and rate of rise in core temperature (7). The magnitude of the practical effect of continuous head cooling can be determined using effect size calculations (9). For the present study an effect size of 0.18 represents a small effect of head cooling on 5-km time-trial performance. Participants did not indicate any change in frequency or type of training during the study and combined with the use of a randomised design, it is unlikely that performance changes are due to a chronic training effect. Consequently, improvements in time-trial performance in the heat can be attributed to head cooling using a cooling cap.

Heart rate and core temperature significantly increased over the course of the running trials for both conditions. However, in accordance with previous head cooling research (1), there was no significant difference between the conditions for either of these two variables. Furthermore, although a meta-analysis (4) highlighted that per-cooling resulted on average in a 0.8 °C decrease in skin temperature, no changes were observed in the current study. Instead, significantly lower forehead temperatures and thermal comfort was observed when using an ice-filled cooling cap, implying that these responses could be associated with an enhancement in performance. Indeed, the cooling cap reduced forehead temperature by 1.6 ± 0.3 °C with this reduction being greater than reported for facial water spraying over the same 5-km time-trial distance (32). It has previously been proposed that due to a greater density of thermal afferents, cooling the forehead has a two-to-five time greater suppression of thermal comfort and sudomotor activitity in comparison to cooling an equivalent area of another skin segment (11). However, it is acknowledged that the inability to apply realistic wind speeds during the time-trials in this study, may have resulted in an artificial increase in core and skin temperature when compared with over-ground running, subsequently overestimating the benefits of the cooling cap (22). Subsequently, further research using realistic airflow is essential to accurately represent the true thermal environment observed in many sporting situations and for evaluating the physiological, performance, and/or psychophysical benefits of ergogenic strategies aimed at reducing thermal strain.

The current study had a focus on performance and consequently is limited in providing definite mechanistic conclusions. Topical reviews have suggested that brain temperature is a major determinant of exercise capacity (26), so a possible reason for the ergogenic effect of cooling the head region is a direct cooling of the cerebral blood and a subsequent reduction in brain temperature. We did not measure brain temperature but it is possible that any alteration in the rate of heat storage will mediate an anticipatory mechanism which adjusts the work rate to prevent body temperature from rising to levels which may cause harm or premature fatigue (37). Additionally, it has previously been suggested that central nervous system mechanisms such as a low dopamine:serotonin ratio in the hypothalamus could mitigate the effects of central fatigue during exercise in the heat (6). Although not equivocal (20), blood prolactin has been utilised as a secondary measure of dopamine and serotonin activity, due to dopaminergic and serotonergic neurons both inhibiting and stimulating pituitary gland secretion (6). Both wearing a neck cooling collar during running (41) and cold fluid ingestion (24) failed to alter the concentration of blood prolactin. However, significantly lower prolactin concentrations were identified with a combination of menthol mouth rinse and facial water spraying (31) and with stand alone facial cooling (1, 23). Given these results, it is possible that lower blood prolactin concentrations could have been present in the head cooling condition. Future research should therefore explore the effects of head cooling using a cooling cap on blood prolactin concentrations, whilst using realistic wind speeds to further simulate the conditions experienced in outdoor running.

Practical Applications: The performance improvement in the current study was achieved by means of a cooling cap filled with ice, and represents a highly practical continuous per-cooling method for use during endurance sports competition. In contrast, other per-cooling methods arguably lack practicality for athletes to adopt during exercise in the heat. For example, despite ice slurry being accessible in some endurance sports, particularly with the recent development of a wide nozzle silicone drinking bottle (19), such beverages are not allowed in long duration events such as Ironman Triathlon, although athletes do have access to ice at aid stations (33). In addition, research has highlighted that ice slurry consumption during cycling caused "uncomfortable" gastrointestinal discomfort in some individuals (30). Further per-cooling strategies that have received recent interest, but would nonetheless be challenging for athletes to implement during exercise, particularly in competitions, includes menthol mouth rinse (34) and palm cooling (16). Ice vests on the other hand, are practically limited due to movement restrictions, additional weight and increased air resistance (12). The cooling cap used for the current study resulted in an additional weight of just 370 g with this weight steadily decreasing throughout the trial, as the ice began to melt. However, it must be pointed out that one participant did comment that the cooling cap was "uncomfortably cold" to begin with, although this did subside as the athlete became accustomed to the cap. Similarly, Minniti et al. (21), discovered that despite a cooling collar improving 15 minute time-trial performance, some participants found it caused discomfort. Nevertheless, the practical strengths of the cooling cap include; 1) the general widespread availabilty of ice at aid stations, especially in hot climates and; 2) the option to select a quantity of ice that is suitable for the athletes needs and the ease at which individuals can add additional ice, should they require. The replacement of ice was not required in the current study due to the relatively short length of the time-trial. However, this could be investigated in future work focusing on longer duration tasks. It is recognized that a reduction in the perceived level of thermal strain and a suppressed heat-loss capacity (i.e. during exercise in hot environments) may have potentially serious implications for the health and well-being of the athlete. Subjective ratings of thermal strain help to regulate exercise intensity (8); therefore, any intervention that manipulates or reduces this feedback over a prolonged duration (e.g. marathon performance) might be dangerous if it permits the athlete to attain a high core body temperature. Further research is required to fully understand the effect of head cooling on the regulation of high intensity physical activity, particularly during prolonged exercise in the heat.

Conclusions: The use of a cooling cap improved 5-km running time-trial performance in the heat. Cooling the head region did not influence physiological variables; however, it did lower the subjective rating of thermal comfort and this could consequently mask the thermal strain experienced by the body. These findings may have an influence on the cooling strategies used by endurance athletes to improve performance.

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