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Assessment of the Omius™ cooling headband during a 70-minute submaximal running effort followed by a 5-km time-trial in hot/humid conditions

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Abstract

Exercise performed under hot/humid conditions can hinder endurance performance. The Omius™ headband (OH) is purported to reduce the perception of heat and improve performance. We examined the impact of OH on selected thermal and cardiovascular functions, subjective perceptions and running performance. Using a randomized crossover protocol, 10 trained male athletes (28 ± 4 yrs) completed two trials (OH and SH (sham headband), 35.0 ± 0.3ºC, 56 ± 3% relative humidity) comprising 70 min of running (60% $\dot{V}O_{2max}$) followed by a 5-km running time-trial (TT). Heart rate, perceived exertion and whole-body thermal comfort did not significantly differ between OH and SH during the submaximal running effort and the TT. Rectal temperature was significantly lower with SH (− 0.18 ± 0.17ºC) than OH prior to the submaximal running effort; this significant difference persisted during the submaximal running effort. Rectal temperature did not differ significantly between conditions during the TT. Forehead temperature was significantly lower with OH than SH during the submaximal running effort, but no significant difference was observed at the end of the TT. Perceived forehead thermal comfort was only significantly lower with OH than SH during the submaximal running effort. TT time did not significantly differ between OH (19.8 ± 1.2 min) and SH (20.2 ± 1.0 min). We conclude that in hot/humid conditions, OH does not improve heart rate, forehead and rectal temperatures, perceived exertion, whole-body and forehead thermal comfort and performance during a 5-km running TT preceded by 70 min of moderate-intensity running.

Keywords: cooling, per-cooling, heat, thermoregulation, performance, running

1. Introduction

Recently, major sporting events such as the 2019 athletic world championship in Doha, the 2021 Tokyo Olympic Games and the women's 2023 Ironman^{TM} triathlon World Championships were held in warm conditions (Eijsvogels et al., 2021). It is anticipated that athletes will compete in warm and humid environments even more often in the coming decades due to rising global temperatures and the increase in the number and frequency of heat extremes (Smith et al., 2016). During intense physical exercise, especially in hot and humid conditions, the metabolic heat produced often exceeds the heat loss through heat dissipation processes which results in an increase in core body temperature (Cheuvront & Haymes, 2001; Kenefick et al., 2007; Wendt, 2007). Indeed, when competing in a humid environment, the heat dissipation capacity via sweat evaporation is reduced due to a diminished water vapour pressure difference between the skin and the air (Kondo et al., 2009). Moreover, the efficacy of the other heat loss mechanisms is shrinking, or even inversed (i.e., dry heat gains), as ambient temperature approaches or surpasses skin temperature (Wendt, 2007). Heat stress is therefore increased when exercising under hot and humid conditions, which may increase 1) core body, skin and brain temperatures; 2) cardiovascular strain; 3) glycogen use; 4) perceived exertion and; 5) reduce muscle recruitment (González-Alonso et al., 1999). Hence, exercising under warm and humid conditions may negatively affect performance and even endanger health (Lei & Wang, 2021).

To reduce thermal and cardiovascular strain when exercising under warm and humid conditions, athletes may resort to the use of cooling strategies before (pre-cooling) or during (per-cooling) exercise (Bongers et al., 2017; Douzi et al., 2020). Pre-cooling strategies reduce cardiovascular and thermal strain, but their effects are substantially reduced after 20-25 min of exercise, rendering them less attractive for prolonged exercise, such as long-distance cycling and running or triathlon. Hence, the use of per-cooling strategies is advocated when exercising for prolonged period of times in warm and humid conditions. Although there is a variety of per-cooling strategies that athletes can use during exercise, one that has been shown to improve endurance performance is head cooling (Ansley et al., 2008; Walters et al., 2017), although its effect on perceived exertion, skin and core body temperatures, heart rate and sweat rate is not conclusive. Therefore, it cannot be ruled out that a placebo effect could be at the root of the effect of head cooling on performance. Regardless, there is a legitimate reason to believe that a true cause and effect relationship could exist between head cooling and performance. Indeed, the hypothalamus is the central integrator for thermoregulation (Nielsen et al., 2001). However, during intense exercise in the heat, there is a substantial increase in brain temperature compared to a thermoneutral environment (Nybo, 2012). So, inhibitory signals from this region caused by an excessive increase in brain temperature can compromise performance (Nybo, 2012). By creating a favorable thermal gradient, cooling the head during exercise could lead to a drop in brain temperature, providing a performance advantage (Cao et al., 2022). The Omius™ headband (OH) is a head cooling device designed to reduce the perception of heat and improve performance in warm conditions. It was introduced to the World in 2019 during the Ironman™ World Championship (Carlson, 2020) and has ever since been commonly used by recreative and competitive athletes. This headband is comprised of 20 porous graphite cubes, which contain 9 small tree dimension metallic towers that act as heat dissipators by increasing the surface area of the forehead. It is purported that the increased forehead heat production during exercise should disperse via conduction along the metallic towers and dissipate to the air by convection (Xu et al., 2005). According to the manufacturer, OH "… increases the evaporative surface area of the skin by 5 times." (Omius website). Thus, OH could potentially produce a cascade of favorable events, i.e., reduce forehead and brain temperatures, as well as whole-body and forehead thermal comfort, which, in concert, would lead to an increase in performance when exercising in warm and humid conditions. However, to the best of our knowledge, this cooling headband has not yet received any scientific attention.

The objective of this study was to determine, in hot and humid conditions, the effect of OH on performance and selected thermal and cardiovascular functions and subjective perceptions during 70 min of submaximal running followed by a 5-km time-trial (TT). We hypothesized that, compared with a sham headband (SH), OH would reduce forehead but not rectal nor mean body temperatures during the submaximal running effort and TT. Furthermore, we supposed that OH would reduce whole-body perception of thermal comfort and perceived exertion during the submaximal running effort but not the TT. Finally, we expected that the headband would improve 5-km running TT time.

2. Methods

2.1. Participants

Ten physically active men (mean ± SD, age: 28 ± 4 years; height: 178 ± 10 cm; body mass: 74 ± 12 kg; body fat: 9.2 ± 2.6%; maximal oxygen consumption ($\dot{V}O_{2max}$): 60 ± 7 mL/kg body mass/min) completed this study. A total of 14 individuals (13 men, 1 woman) were initially recruited, but two individuals did not meet the inclusion criteria for $\dot{V}O_{2max}$, and 2 withdrew after the familiarisation trial. Inclusion criteria were: 1) healthy and between the age of 18-50 years; 2) physically active (> 8 h of aerobic training per week, including running); 3) be able to run at least 90 min continuously; 4) body mass index < 30 kg/m^2; 5) $\dot{V}O_{2max}$ for women ≥ 47 and men ≥ 52 mL/kg body mass/min, which is considered as a performance level 2 according to Pauw et al. (2013). Exclusion criteria were: 1) intolerance to blood punctures; 2) chronic use of anti-inflammatory; 3) cold or flu; 4) diabetes; 5) heat intolerance; 6) lower limb injuries; 7) medications that may alter fluid balance and body temperature; 8) high blood pressure; 9) excessive accumulation of earwax (determined with an otoscope) in the ear canal; 10) susceptibility to developing muscle cramps during exercise and; 11) being pregnant or breastfeeding. The study and procedures were thoroughly explained, and participants gave their written informed consent to participate in this study. The CIUSSS Estrie-CHUS Ethics Committee (2023-4848) approved all experimental procedures.

2.2. Overview of the study

After determining eligibility, participants underwent a preliminary visit where baseline measurements were taken. Then, no more than 10 days following the first visit, participants completed a familiarization trial where they experienced the same exercise protocol than that used for the upcoming experiments. Finally, participants completed 2 experimental trials (SH and OH) separated by 7 to 10 days, which were conducted at the same time of day.

2.3. Preliminary visit

The height of the participants, wearing only socks, was measured to the nearest 0.5 cm using a wall stadiometer, body mass, while post-void and in the nude, with a digital scale (BX-300+, Altron Systems, USA, ± 20 g), and blood pressure and resting heart rate using a digital sphygmomanometer (Welch-Allyn 420 series, USA) after the participants had been seated for a period of 2 min. Following these measurements, the left ear canal of the participants was closely examined with an otoscope (HS-OT10G, Honsun Medical, Zhejiang, China) to determine the extent of the presence of earwax. Then, fat mass and fat free mass (FFM) were measured with the dual-energy X-ray absorptiometry technology (Lunar Prodigy, GE Healthcare, USA). Finally, $\dot{V}O_{2max}$ was determined with a metabolic analyzer (Cosmed Quark CPET, Cosmed, USA) calibrated according to the manufacturer instructions. Participants started walking at 5 km/h on a motorized treadmill (model TMX428 Trackmaster, Newton, KS, USA) with 0% grade for 1 min, with further increments of 1 km/h occurring every 1 min until the participants could not continue. The $\dot{V}O_{2max}$ was confirmed when at least two of those criteria were reached: 1) respiratory exchange ratio ≥ 1.1; 2) theoretical maximal heart rate (220-age) was reached and; 3) $\dot{V}O_2$ plateau concurrent to an increase in speed (Howley et al., 1995). At the end of this visit, pre-experimental instructions regarding the cleaning of the left ear canal and preparation for the familiarization trial were provided to participants.

2.4. Pre-experimental protocol

Participants were required to fill a dietary log (nutrition and hydration) during the 24 h period preceding the familiarization trial, which they replicated for the 24 h period preceding the two experiments. Participants refrained from consuming diuretics, with the exception of caffeine (to prevent symptoms of withdrawal), during the 24 h period preceding the familiarization trial and experiments as well as from taking any supplements in the 48 h period preceding these visits. Furthermore, to ensure that participants arrived at the laboratory in an euhydrated state for both the familiarization trial and experiments, they drank 250 mL of water 120 min before going to sleep the night before these visits and 250 mL 60 min before arriving at the laboratory. Participants went to bed at the same time of day the nights preceding the familiarization trial and experiments and maintained their training routine over the last 24 h period before these visits. Finally, prior to all the upcoming visits participant were asked to refrain from exercise for the last 8 h leading to, and to stop eating and drinking for the last 60 min prior to, their arrival at the laboratory.

2.5. Familiarization trial

To accustom participants with all the procedures and equipment to be used in the experiments, minimize any learning effect and determine the correct running speed for the submaximal running effort, a familiarization trial was performed (Hopkins et al., 1999). During this visit, participants underwent a 70 min running effort at 60% $\dot{V}O_{2max}$, which was immediately followed by a 5-km TT. The exercise protocol was performed under the same experimental conditions as those used during the upcoming experiments, with the exception that no headband was worn, and no spraying of the forehead was performed. The participants' $\dot{V}O_2$ was measured continuously during the first 5 min of the submaximal running effort, and the appropriate running velocity was confirmed when $\dot{V}O_2$ remained within ± 150 mL of the targeted $\dot{V}O_2$ for an entire minute. The total volume of water that participants received during the run was based on the assumption that the 5-km TT would be completed in 20 min and, hence, that the entire running effort would be of 90 min.

2.6. Experimental protocol

Figure 1 illustrates the experimental protocol. Each experiment was divided into 4 phases: 1) arrival at the laboratory and baseline data collection; 2) 70 min submaximal running effort at 60% $\dot{V}O_{2max}$; 3) 5-km TT performance and; 4) end of the experiment and data collection. At their arrival at the laboratory, participants first voided their bladder in a portable urinal and a midstream urine sample was collected to assess urine specific gravity, osmolality and color. Participants then inserted a telemetric pill into their rectum, their body mass was assessed and, in preparation for capillary blood collection, they sat quietly for 10 min with their hand immersed in 40°C water. Finally, participants were instrumented with a heart rate chest strap and 4 skin probes and then remained silent for 5 min at which time measurements of heart rate, rectal, skin, forehead and aural canal temperatures as well as subjective perceptions were taken. Participants were then transferred to the environmental chamber where they mounted the motorized treadmill and remained silent for 5 min. During that period, the temperature and humidity of the environmental chamber were measured as well as the wind speed from the ventilators facing the participants. Then, measurements of heart rate, rectal, skin, forehead and aural canal temperatures as well as subjective perceptions were taken again. Following this, the headband was placed on the forehead of the participants, water was sprayed on the headband, and immediately thereafter the submaximal running effort started. The subjective perceptions were measured every 5 min. At min 5, 15, 25, 35, 45, 55, 65 and 70 during the submaximal running effort, participants stopped running by placing their feet on the sides of the treadmill, the ventilators were stopped and measurements of heart rate, rectal, skin, forehead and aural canal temperatures were taken. Then, with the exception of min 70, participants consumed water, running was resumed, and ventilators restarted. Stop times were standardized to 45 sec. Water was provided based on a rate of consumption of 500 mL/h/70 kg body mass. Each serving represented $^{1}/_{6}$ of the hourly volume to be consumed. Water was provided at a temperature of 20°C, since it has been observed that the water served at aid stations during Ironman™

triathlon races is between 14 and 26ºC (Burdon et al., 2013). At the 45 min mark, the participants ingested an energetic gel (GU, Berkeley, Ca, USA) containing 22 g of carbohydrates. The 5-km TT started immediately following the last treadmill stopped at min 70 of the submaximal running effort. The participants could adjust their speed throughout the TT and did not have access to any metrics such as speed, distance to be completed or elapsed time but were informed of the distance ran. Verbal encouragements were not provided during the TT in order to avoid bias from the experimenter. Heart rate, rectal and skin temperatures, as well as subjective perceptions were measured every 1 km during the TT. At the end of the TT, the forehead and aural canal temperatures were measured, and a capillary blood sample was taken. The headband, heart rate chest strap and the skin probes were removed from the participants. The participants were then dried and weighted without their shoes, but with a correction for the mass of clothes worn and sweat trapped in them. Finally, a midstream urine sample was collected.

2.7. Measurements and headbands

2.7.1. Heart rate and rectal, skin, forehead, aural canal and mean body temperatures

Heart rate was measured with a Garmin™ chest electrode (Garmin, Olathe, KS, USA) and signals were interpreted using the Golden Cheetah™ software. Rectal temperature was measured a calibrated telemetric pills (CoreTemp™, HQ Inc, Palmetto, FL, USA) inserted just beyond the anal sphincter, as per the specifications found in Gosselin et al. (2019). Each pill was reused for a total of 50 h (Pancrate et al., 2020); hence, the pills were shared by several participants, but each participant used the same pill for the familiarization trial and both of their experiments. The pills were sterilized after every utilization with a solution of 2.5% glutaraldehyde (MetriCide 28, Metrex, Orange, CA, USA). Skin temperature was determined by placing calibrated YSI 409 B probes (Yellow Springs Instrument, Yellow Springs, OH, USA) on the left side of the body at the the chest, forearm, thigh and calf level. The skin probes were held in place with the use of hypafix dressing tape and connected to a USB-TEMP data acquisition box (MC measurement computing, Norton, MA, USA).

Mean skin temperature (T_{skin}) was calculated according to Ramanathan (1964) using the following formula :

$$T_{skin} = (0.3 \times T_{chest}) + (0.3 \times T_{forearm}) + (0.2 \times T_{thigh}) + (0.2 \times T_{calf}), \quad (1)$$

where T is temperature.

Forehead temperature was measured at the center of the forehead, 1 cm above the procerus, with an infrared thermometer (Mastercraft, Vonore, TN, USA) held perpendicularly approximately 2.5 cm above the surface of the forehead (Dolibog et al., 2022). The skin emissivity was set at 0.98 (Steketee, 1973). Forehead temperature measurement was performed after the headband had been lifted upward slightly and the forehead dried with a clean towel (Morán-Navarro et al., 2019). Then, the headband was placed back to its initial position and sprayed throughout with 6 mL of water at 20°C. Aural canal temperature was measured using an infrared thermometer (Braun Thermoscan 7, Bethlehem, PA, USA) designed for tympanic temperature assessment. In order to insert the probe tip at close proximity of the tympanic membrane, the participants' helix (the outer rim of the ear) was pulled up and back. Furthermore, inside the environmental chamber, when the aural canal temperature was measured, the fans were stopped because this measurement can be affected when air is blown in direction of the head of the participants (Deschamps et al., 1992; Shiraki et al., 1988). Aural canal temperature was used in the present study as an index of brain temperature (Notley et al., 2018). Indeed, the tympanic temperature has been shown to provide a good appreciation of the brain temperature (Mariak et al. 1994). When used according to the manufacturer instructions, the Braun Thermoscan 7 can detect changes in core body temperature during exercise (Fenemor et al., 2020; Morán-Navarro et al., 2019).

Mean body temperature was computed from rectal and mean skin temperatures using the formula proposed by Baum et al. (1976):

$$\text{Mean body temperature} = (0.87 \times T_{rec}) + (0.13 \times T_{skin}), \tag{2}$$

where T_{rec} and T_{skin} denote rectal and mean skin temperatures, respectively.

2.7.2. Subjective measures

Perceived exertion was measured using the 6-20 Borg rating scale (Borg, 1998). Whole-body thermal comfort and forehead thermal comfort were measured with a scale ranging from 1 to 7 (1: too cool; 2: cool; 3: comfortably cool; 4: comfortable; 5: comfortably warm; 6: warm; 7: too warm), as found in Schweiker et al. (2017).

2.7.3. Urinary measurements, sweat loss and dehydration level

Urine volume was measured gravimetrically using a digital scale (Symmetry, Cole-Parmer, Quebec, Canada), urine specific gravity using a refractometer (PAL-10S, Atago, Bellevue, WA, USA) (Dion et al., 2013), urine color with a validated 8-point scale (Armstrong et al., 1998) in a well-lit room and immediately after collection and urine osmolality using the freezing point depression technique (Micro-Osmometer, Osmette, Precision Systems Inc., Natick, MA, USA). Sweat loss was computed from the before to after difference in body mass, with corrections for fluid intake and urine production. Losses of mass associated with the respiratory exchange of O_2 and CO_2, as well as respiratory water losses, were not considered in the calculation of sweat loss and were assumed to be similar between experiments. Sweat loss was corrected by exercise time (h) to obtain sweat rate.

2.7.4. Capillary blood measurements

The finger was first cleaned and disinfected with 70% isopropyl alcohol. Then, a high blood flow lancing device (Capiject, Terumo, Vaughan, Ontario, Canada) was used to prick the finger at a depth of ~2 mm. After the first blood drop had been swiped away, ~400 μL of blood was collected in a capillary lithium-heparin tube. Blood was collected to measure hemoglobin using the Alere H2 Hemopoint system (Alere, Lowell, MA, USA), hematocrit using the centrifugation technique and blood osmolality with the freezing point depression technique (Micro-Osmometer, Osmette, Precision Systems Inc., Natick, MA, USA). Capillary hemoglobin and hematocrit values have been shown to be highly correlated to venous blood hemoglobin and hematocrit values (Hutler et al. 2000). Furthermore, capillary blood osmolality has also been shown to be comparable to venous blood osmolality (Bergin-Taylor et al., 2023). The Dill & Costill (1974) equation was used to estimate plasma volume changes.

2.7.5. Headbands

Two Omius™ headbands were purchased directly from the manufacturer (see Figure 1 in the Supplementary Material section). For SH, the 20 cooling cubes were removed from the original headband and replaced by 20 pieces that were 3D printed with a Ultimaker S5 printer (Cadmicro, Montreal, Canada). The pieces were conceived with white Tough PLA 3D printing filament (Voxel factory, Longueuil, Canada) and sprayed with black paint (Fusion, Krylon, Cleveland, USA) to mimic the speckled look of the OH cubes. When OH is placed on the forehead, a cooling sensation can immediately be felt. Hence, to limit the difference in cold sensation upon installing the headbands, SH was placed in a refrigerator maintained at a temperature of 4°C the day before the experiment, while OH was kept at an ambient temperature of 20-22°C (laboratory temperature).

3. Statistical analysis

All statistical analyses were performed using Prism 10.1.0. (Graphpad Prism, Dotmatics, Boston, MA, USA), whereas sample size requirement was computed using MedCalc 20.211 (Ostend, Belgium). Shapiro-Wilk tests were used to analyze data normality prior to analysis. Dependent t-tests were used to compare results pertaining to hydration state at arrival at the laboratory (body mass, urine specific gravity, urine osmolality and urine color) and environmental conditions (relative humidity, ambient temperature and simulated wind speed). Given that normality of distribution was not respected for the 5-km TT performance, a Wilcoxon test was executed to compare the two conditions. Two factors (condition × time) repeated-measures ANOVAs were used to determine the effect of the conditions on variables repeatedly measured through the experiments. When sphericity was violated, a Greenhouse-Geisser correction was applied. Statistical significance was set at $p \leq 0.05$ and results are reported as means ± SD. As TT completion time differed within and between participants, measurements taken repeatedly during this time-period were made comparable within participants and between conditions with a transformation of time (min) to % completion time. The difference in performance time between the two conditions was calculated ((OH TT time – SH TT time)/ OH TT time * 100%) and is presented as means ± SD and the 95% confidence interval.

A power computation *a priori* performed indicated that the present study had an 80% chance to detect a statistically significant difference between the two conditions based on a sample size of 10 participants, an intra-participant test-retest standard deviation of 30 sec for the 5-km running TT (Laursen et al., 2007), a significance level of $\alpha = 0.05$ and a minimal difference between the two conditions set at 30 sec.

4. Results

4.1. State of hydration of participants at arrival at the laboratory and ambient conditions

Table 1 shows the hydration state-associated variables at the arrival at the laboratory. Collectively, they indicate that participants arrived at the laboratory in a similarly well hydrated state. Relative humidity (SH: 56.4 ± 3.1; OH: 55.3 ± 2.6%; $p = 0.371$), ambient temperature (SH: 35.0 ± 0.3; OH: 34.9 ± 0.3°C; $p = 0.340$) and simulated wind speed (SH: 14.0 ± 1.2; OH: 12.8 ± 2.4 km/h; $p = 0.113$) during the running efforts inside the environmental chamber did not significantly differ between conditions.

4.2. Body temperatures

4.2.1. Rectal, mean skin and body, forehead and aural canal temperatures

Figure 2 shows the changes in rectal (A and B) and skin (C and D) temperatures during the submaximal running effort and the 5-km TT. Rectal temperature was significantly lower with SH (− 0.18 ± 0.17°C; $p = 0.009$) than OH prior to the start of the submaximal running effort. This difference persisted during the submaximal running effort, where rectal temperature was, on average, 0.21°C lower with SH than OH ($p = 0.018$). Rectal temperature increased over time during the submaximal running effort ($p < 0.0001$), with no time × condition interaction ($p = 0.660$). At the beginning of the 5-km TT, rectal temperature was significantly ($p = 0.048$) higher with SH (39.37 ± 0.39°C) than OH (39.15 ± 0.40°C). Rectal temperature increased significantly during the TT for both SH and OH ($p < 0.0001$), with no condition ($p = 0.074$), nor time × condition interaction effect ($p =$

0.764). Mean skin temperature significantly increased during both the submaximal effort ($p < 0.0001$) and the 5-km TT ($p = 0.002$) for both OH and SH, but it did not differ between conditions during both the submaximal running effort ($p = 0.263$) and the 5-km TT ($p = 0.977$). Furthermore, there was no time × condition interaction effect during the submaximal effort ($p = 0.875$), but there was a time × condition interaction effect during the 5-km TT ($p = 0.047$). Mean body temperature was significantly lower with SH (− 0.17 ± 0.31ºC, $p = 0.011$) than OH prior to the submaximal running effort. Mean body temperature increased during the submaximal running effort and remained lower with SH ($p = 0.045$), but there was no time × condition interaction ($p = 0.746$). For the 5-km TT, a time ($p < 0.0001$), but no condition ($p = 0.083$), nor time × condition interaction ($p = 0.421$) effects were observed. Forehead temperatures observed during the submaximal running effort are shown in Figure 3. Forehead temperature increased through time ($p < 0.0001$), with condition ($p = 0.007$), but no time × condition interaction ($p = 0.259$). On average, forehead temperature was 0.60°C lower with OH compared with SH during the submaximal running effort. At the end of the 5-km TT, forehead temperature was lower with OH (35.7 ± 1.1°C) than SH (36.5 ± 0.9°C), but this difference did not reach significance ($p = 0.054$). As their validity was uncertain, data related to aural canal temperatures are not presented. We believe that this measurement was contaminated by the air blown to the participants' face between each measurement periods, thereby the aural canal and tympanic membrane were likely overly cooled when measurements were taken.

4.3. Heart rate

Figure 4 shows the changes in heart rate during the submaximal running effort (A) and 5-km TT (B). Hear rate increased over time during both the submaximal running effort ($p <$

0.0001) and the 5-km TT ($p < 0.0001$), with no conditions ($p \geq 0.645$) and no time × condition interaction ($p \geq 0.068$).

4.4. Water intake, sweat loss, dehydration, and plasma volume change

In both conditions the average water intake during the running effort was 778.6 ± 141.4 mL. There was no significant difference between SH and OH for sweat loss (SH: 2.6 ± 0.3; OH: 2.7 ± 0.3 L; $p = 0.720$), exercise-induced dehydration (SH: 3.8 ± 0.3; OH: 3.7 ± 0.4% body mass; $p = 0.740$) and sweat rate (SH: 2.1 ± 0.40; OH: 2.0 ± 0.4 L/h; $p = 0.360$). Plasma volume decreased similarly ($p = 0.760$) during exercise by 2.4 ± 6.4% with SH and 1.4 ± 10.0% with OH.

4.5. Subjective perceptions

The changes in perceived exertion (A, B), overall thermal comfort (C, D) and forehead thermal comfort (E, F) during the submaximal running effort and 5-km TT are shown in Figure 5. All subjective perceptions increased over time during both the submaximal running effort and 5-km TT ($p < 0.001$). Compared with SH, OH did not lower perceived exertion during the submaximal running effort ($p = 0.246$) nor during the 5-km TT ($p = 0.450$). Whole-body thermal comfort was not different between conditions both during the submaximal running effort ($p = 0.068$) and the 5-km TT ($p = 0.652$). Furthermore, there was no time × condition interaction effect during the submaximal running effort ($p = 0.429$) and the 5-km TT ($p = 0.800$). Forehead thermal comfort was lower during the submaximal running effort with OH compared to SH ($p = 0.008$), but there was no difference during the 5-km TT ($p = 0.201$). Furthermore, there was no time × condition interaction effect during the submaximal running effort ($p = 0.411$) and the 5-km TT ($p = 0.244$).

4.6. 5-km running time-trial

Figure 6 shows the mean as well as individual 5-km running TT times with both SH and OH. Running times for the 5-km TT did not differ between conditions with 20.2 ± 1.0 min with SH and 19.8 ± 1.2 min with OH (p = 0.430), which translates to a difference of 2.2 ± 7.1% (95% CI: − 7.2 to 2.9%) in favor of OH.

5. Discussion

The effect of the Omius™ headband on thermal, cardiac and perceptual strain, as well as on endurance performance, has never been scientifically determined. Yet, this device is used by many professional and elite triathletes competing in triathlon events. For instance, this cooling device was used by the men and women winners of the 2023 Ironman™ triathlon World Championship (Ironman, 2023a, 2023b). Results of the current study show that although OH reduced forehead temperature and perceived forehead thermal comfort, it did not positively impact the control of mean body temperature, as indicated by an incapacity to reduce rectal and mean skin temperatures, compared with SH. Furthermore, OH did not improve 5-km TT performance in warm and humid conditions.

The head is an ideal location for the application of a cooling strategy, since 1) adiposity level is low, therefore increasing thermal conductivity (Cao et al., 2022), 2) vasoconstrictor innervation is weak (Simmons et al., 2008), 3) the vascular system is well-developed, thereby contributing in significantly increasing blood influx (Simmons et al., 2008) and 4) thermo-sensitive alliesthesia is important (Cotter & Taylor, 2005). Surprisingly, the number of studies exploring the effect of forehead, head or facial cooling on thermoregulation or performance during exercise is limited (Ansley et al., 2008; Katsuura et al., 1989; Mündel et al., 2007; Walters et al., 2017; Watanuki, S., 1993). Hence, the current study is a worthwhile addition to the literature.

As we anticipated, OH reduced forehead, but not rectal and mean body temperatures during both the submaximal running effort and 5-km TT. Other studies have also observed that head or face cooling is not associated with a reduction in core body temperature during exercise. Indeed, Desruelle & Candas, (2000b) have shown that cooling of the head did not alter esophageal temperature during cycling exercise in the heat (36ºC). On the other hand, Mündel et al. (2007) and Ansley et al. (2008) observed that cooling the face did not alter rectal temperature while cycling under warm conditions. However, Katsuura et al. (1989) have observed that head cooling while cycling wearing a cap with cool water circulating through tubes, resulted in an increase in rectal temperature compared to a controlled condition possibly due to a reduction in sweating. Therefore, our results indicate that the surface area of the forehead or the cooling effect produced by the OH at the skin level are likely not substantial enough to impact rectal temperature, contrary to other external cooling strategies such as cooling the whole head through wearing a liquid conditioned cap or cooling the torso through the wearing of cooling vests. Indeed, it has been observed that cooling larger body areas during exercise is more effective than cooling smaller areas (Douzi et al., 2019). Alternatively, the lack of proximity of the forehead to major blood vessels within the brain may limit the transport of cooled blood to the periphery and, hence, cooling of the core.

The ability to attenuate cardiovascular strain during prolonged exercise is thought to represent a powerful manner through which performance can be preserved or enhanced (Hasegawa et al., 2005; Stevens et al., 2017). However, our results demonstrate that there was no difference in heart rate between SH and OH both during the submaximal running effort and 5-km TT. Our results are in line with those of Ansley et al. (2008) who also observed no effect on heart rate when participants were head cooled during a cycling effort at 75% of $\dot{V}O_{2max}$ until volitional fatigue under warm conditions (29°C and 50% relative humidity). However, Watanuki (1993) observed that head cooling (wearing a liquid conditioned cap) reduced the heart rate and cardiac output of participants running at 50% of $\dot{V}O_{2max}$ in a warm environment (25°C and 56% relative humidity). Mündel et al. (2007) also observed a decrease in heart rate (~5 beats/min) with head cooling compared to a control condition while cycling at 65% of peak power output in warm conditions. The observed decrease in heart rate, as reported in the two studies previously mentioned, can be attributed to two distinct physiological processes. Firstly, cooling the facial area may stimulate the trigeminal nerve, leading to a change in vagal tone, which in turn reduces the heart rate (Mündel et al., 2007). Secondly, cooling the face may cause the blood vessels beneath the skin to vasoconstrict, potentially enhancing venous return, increasing stroke volume, and consequently lowering heart rate (Mündel et al., 2007). Thus, it may be inferred that the cooling effect of OH is potentially insufficient to either activate the trigeminal nerve or induce vasoconstriction of the facial vessels.

Whole-body thermal comfort and perceived exertion did not differ between the two conditions during the submaximal running effort and the 5-km TT. This contrasts with the findings of Ansley et al. (2008) who observed a significant reduction in perceived exertion when participants were head cooled via facial fanning and having a fine mist of water sprayed on their face while cycling at 75% of $\dot{V}O_{2max}$ until volitional fatigue in a warm environment (29ºC, 50% relative humidity). However, Ansley et al. (2008) did not measure the perception of heat or thermal comfort. Similarly, Mündel et al. (2007) reported a reduction in the sensation of heat in participants cycling for 40 min at 65% of peak aerobic power when cooled by having cold water (4ºC) sprayed on their face. Furthermore, they observed that head cooling reduced perceived exertion only at the end of the exercise period. Thus, it appears that the cooling effect of OH is not as effective as the head cooling strategies implemented by Ansley et al. (2008) and Mündel et al. (2007). In the present study, the OH only had an effect on forehead thermal comfort during the submaximal running effort but not the 5-km TT, which may suggest that the cooling effect of OH is only perceptible at lower intensity.

We observed no difference between conditions on 5-km TT performance. This can be potentially explained by the fact that OH had no effect on rectal temperature, heart rate, perceived and whole-body thermal comfort, which are crucial factors associated with exercise performance in warm conditions (González-Alonso, 1999; Nybo et al., 2014). This result opposed that of Ansley et al. (2008) who observed a 51% improvement in cycling time to exhaustion at 75% of $\dot{V}O_{2max}$ in a warm environment with head cooling, compared to a control condition. Even though, they did not observe an effect of the head cooling on rectal temperature, Ansley et al. (2008) observed that this cooling strategy reduced the tympanic temperature, which may indicate a decrease in brain temperature (Mariak et al. 1994). Ansley et al. (2008) used fans facing the head of the participants and sprayed a mist of water at 30 sec intervals over the participants' head, which may indicate that the combination of fans and water spraying is more effective at cooling the head than the OH. In the present study, it was anticipated that OH could have contributed to an increase in 5-km TT performance through an attenuated increase in brain temperature or by altering the pacing behavior via a lowering of the thermal comfort. Indeed, the brain is considered the organ that is the most sensitive to changes in core body temperature (Brinnel et al., 1987) and an increase in brain temperature during exercise in warm conditions is thought to be one of the causes of the attenuated ability to voluntary activate skeletal muscles that is observed under increases in core body temperature (Nybo & Nielsen, 2001). Furthermore, it was anticipated that OH, similarly to the ingestion of menthol, would have improved the thermal comfort of the participants and would have altered their pacing strategy, resulting in a higher running velocity during the 5-km TT, compared to the control condition, but it was not the case (Flood et al., 2017; Parton et al., 2021).

The present study has strength and limitations. We controlled for the placebo effect by comparing the OH to a SH, which had an identical appearance and provided the same cooling sensation when placed on the forehead at the start of the running exercise. The headbands were not sprayed with water during the TT. Hence, it is possible that OH was not wet enough during the 5-km TT to provide sufficient cooling of the forehead, thereby preventing us to observe a performance improvement through an alliesthesia effect (Cao et al., 2022). Results only apply to the specific exercise conditions and environmental conditions used in the current study. The impact of OH could have been different under less humid conditions, since humidity reduces the evaporative capacity of water and, hence, heat loss.

5. Conclusion

This study demonstrated that OH reduces forehead temperature and forehead thermal comfort but not rectal temperature, heart rate and perceived exertion during 70 min of submaximal running effort in the heat. Furthermore, it did not improve 5-km TT performance following the submaximal running effort. Therefore, the Omius^{TM} headband is unlikely to improve running velocity in the last few kilometers of an endurance event held in hot and humid conditions.

Credit auhtorship statement

Conceptualization and methodology: AJD and EDBG; Data collection: AJD and FA; Data analysis and interpretation: AJD and EDBG; Project administration: EDBG; Supervision: EDBG; Writing - original draft: AJD; Writing - review & editing: AJD, TAD, FA and EDBG.

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Declaration of competing interest

The authors have no conflicts of interest.

Data Availability Statement

Data used for this study can be found at this link: 10.6084/m9.figshare.25568529

We grant permission to use the data for double verification or meta-analysis purposes.

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References

Ansley, L., Marvin, G., Sharma, A., Kendall, M., Jones, D., & Bridge, M. (2008). The effects of head cooling on endurance and neuroendocrine responses to exercise in warm conditions. *Physiological Research*, 863-872. https://doi.org/10.33549/physiolres.931260

Armstrong, L. E., Soto, J. A., Hacker, F. T., Jr., Casa, D. J., Kavouras, S. A., & Maresh, C. M. (1998). Urinary indices during dehydration, exercise, and rehydration. I*nternational Journal of Sport Nutrition*, 8: 345-355.

Baum, E., Bruck, K., & Schwennicke, H. P. (1976). Adaptive modifications in the thermoregulatory system of long-distance runners. *Journal of Applied Physiology, 40(3)*, 404-410. https://doi.org/10.1152/jappl.1976.40.3.404

Bergin-Taylor, M. K., Funnell, D. M. P., Ferguson, D. R., Mears, D. S. A., & James, D. L. J. (2014). Serum osmolality measured in fingertip capillary blood is comparable to serum osmolality measured in venous blood. *Applied Physiology Nutrition, and Metabolism*, 1;49(1):121-124. doi: 10.1139/apnm-2022-0358.

Bongers, C. C. W. G., Hopman, M. T. E., & Eijsvogels, T. M. H. (2017). Cooling interventions for athletes : An overview of effectiveness, physiological mechanisms, and practical considerations. *Temperature*, *4*(1), 60-78. https://doi.org/10.1080/23328940.2016.1277003

Borg, G. (1998). Borg's Perceived Exertion and Pain Scales, Human Kinetics: Champaign, IL, USA.

Brinnel, H., Nagasaka, T., & Cabanac, M. (1987). Enhanced brain protection during passive hyperthermia in humans. *European Journal of Applied Physiology and Occupational Physiology*, *56*(5), 540-545. https://doi.org/10.1007/BF00635367

Burdon, C. A., Johnson, N. A., Chapman, P. G., Muhamed, A. M. C., & O'Connor, H. T. (2013). Case Study : Beverage Temperature at Aid Stations in Ironman Triathlon. *International Journal of Sport Nutrition and Exercise Metabolism*, *23*(4), 418-424. https://doi.org/10.1123/ijsnem.23.4.418

Cao, Y., Lei, T.-H., Wang, F., Yang, B., & Mündel, T. (2022). Head, Face and Neck Cooling as Per-cooling (Cooling During Exercise) Modalities to Improve Exercise Performance in the Heat : A Narrative Review and Practical Applications. *Sports Medicine - Open*, *8*(1), 16. https://doi.org/10.1186/s40798-022-00411-4

Carlson, T. (2020, January 02). *2019 Kona-Top 15 Pro Men Run Gear*. Slowtwitch. https://www.slowtwitch.com/Features/2019_Kona_-_Top_15_Pro_Men_Run_Gear_7557.html (accessed March 10th 2024)

Cheuvront, S. N., & Haymes, E. M. (2001). Thermoregulation and Marathon Running : Biological and Environmental Influences. *Sports Medicine*, *31*(10), 743-762. https://doi.org/10.2165/00007256-200131100-00004

Cheuvront, S. N., Kenefick, R. W., Montain, S. J., & Sawka, M. N. (2010). Mechanisms of aerobic performance impairment with heat stress and dehydration. *Journal of Applied Physiology*, *109*(6), 1989-1995. https://doi.org/10.1152/japplphysiol.00367.2010

Cotter, J. D., & Taylor, N. A. S. (2005). The distribution of cutaneous sudomotor and alliesthesial thermosensitivity in mildly heat-stressed humans : An open-loop approach: Local cutaneous thermosensitivity. *The Journal of Physiology*, *565*(1), 335-345. https://doi.org/10.1113/jphysiol.2004.081562

Deschamps, A., Levy, R. D., Cosio, M. G., Marliss, E. B., Magder, S. (1992). Tympanic Temperature Should Not be Used to Assess Exercise Induced Hyperthermia. *Clinical Journal of Sport Medicine*, 2(1), 27-32.

Desruelle, A. V., & Candas, V. (2000). Thermoregulatory effects of three different types of head cooling in humans during a mild hyperthermia. *European Journal of Applied Physiology and Occupational Physiology*, *81*(1-2), 33-39. https://doi.org/10.1007/PL00013794

Dill, D. B., & Costill, D. L. (1974). Calculation of percentage changes in volumes of blood, plasma, and red cells in dehydration. *Journal of Applied Physiology*, *37*(2), 247-248. https://doi.org/10.1152/jappl.1974.37.2.247

Dion, T., Savoie, F. A., Asselin, A., Gariepy, C., & Goulet, E. D. B. (2013). Half-marathon running performance is not improved by a rate of fluid intake above that dictated by thirst sensation in trained distance runners. *European Journal of Applied Physiology*, *113*(12), 3011-3020. https://doi.org/10.1007/s00421-013-2730-8

Dolibog, P., Pietrzyk, B., Kierszniok, K., & Pawlicki, K. (2022). Comparative Analysis of Human Body Temperatures Measured with Noncontact and Contact Thermometers. *Healthcare*, *10*(2), 331. https://doi.org/10.3390/healthcare10020331

Douzi, W., Dugué, B., Vinches, L., Al Sayed, C., Hallé, S., Bosquet, L., & Dupuy, O. (2019). Cooling during exercise enhances performances, but the cooled body areas matter : A systematic review with meta-analyses. *Scandinavian Journal of Medicine & Science in Sports*, *29*(11), 1660-1676. https://doi.org/10.1111/sms.13521

Douzi, W., Dupuy, O., Theurot, D., Smolander, J., & Dugué, B. (2020). Per-Cooling (Using Cooling Systems during Physical Exercise) Enhances Physical and Cognitive Performances in Hot Environments. A Narrative Review. *International Journal of Environmental Research and Public Health*, *17*(3), 1031. https://doi.org/10.3390/ijerph17031031

Eijsvogels, T. M. H., de Korte, J. Q., & Bongers, C. C. W. G. (2021). Beat the heat : How to become a gold medalist at the Tokyo Olympics. *Temperature*, *8*(3), 203-205. https://doi.org/10.1080/23328940.2021.1944005

Fenemor, S. P., Gill, N. D., Sims, S. T., Beaven, C. M., & Driller, M. W. (2020). Validity of a Tympanic Thermometer and Thermal Imaging Camera for Measuring Core and Skin Temperature during Exercise in the Heat. *Measurement in Physical Education and Exercise Science*, *24*(1), 49-55. https://doi.org/10.1080/1091367X.2019.1667361

Flood, T. R., Waldron, M., & Jeffries, O. (2017). Oral l-menthol reduces thermal sensation, increases work-rate and extends time to exhaustion, in the heat at a fixed rating of perceived exertion. *European Journal of Applied Physiology*, *117*(7), 1501-1512. https://doi.org/10.1007/s00421-017-3645-6

González-Alonso, J., Teller, C., Andersen, S. L., Jensen, F. B., Hyldig, T., & Nielsen, B. (1999). Influence of body temperature on the development of fatigue during prolonged exercise in the heat. *Journal of Applied Physiology*, *86*(3), 1032-1039. https://doi.org/10.1152/jappl.1999.86.3.1032

Gosselin, J., Beliveau, J., Hamel, M., Casa, D., Hosokawa, Y., Morais, J. A., Goulet, E.D.B. (2019). Wireless measurement of rectal temperature during exercise:

Comparing an ingestible thermometric telemetric pill used as a suppository against a conventional rectal probe. *Journal of Thermal Biology*, *83*, 112-118.

Hasegawa, H. Takatoru, T., Komura, T., & Yamasaki, M. (2005). Wearing a cooling jacket during exercise reduces thermal strain and improves endurance exercice in a warm environment. *Journal of Strength & Conditioning Research*, *19*(1), 122-128. http://doi.org/ 10.1519/14503.1.

Hopkins, W. G., Hawley, J. A., & Burke, L. M. (1999). Design and analysis of research on sport performance enhancement: *Medicine & Science in Sports & Exercise*, *31*(3), 472-485. https://doi.org/10.1097/00005768-199903000-00018

Howley, E. T, Bassett, D. R. Jr., & Welch, H. G. (1995). Criteria for maximal oxygen uptake: review and commentary. *Medicine and science in sports and exercise*. 27(9):1292–301

Hutler, M., Beneke, R., & Boning, D. (2000). Determination of circulating hemoglobin mass and related quantities by using capillary blood. *Medicine and Science in Sports Exercise*, *32*(5), 1024-1027. https://doi.org/10.1097/00005768-200005000-00022

Ironman. (2023a). Sam Laidlow clinches home-turf-win. https://www.ironman.com/news_article/show/1283987

Ironman. (2023b). Lucy Charles-Barclay (GBR) soars atop stellar field to become the 2023 Vinfast Ironman World Champion in Kailua-Kona, Hawaii. https://www.ironman.com/news_article/show/1288098

Katsuura, T., Ise, N., Onoda, H., Okada, A., & Kikuchi, Y. (1989). Effect of head cooling on man at rest and during exercise under heat stress. *Annals of Physiological Anthropology*, 8(1), 49-50.

Kenefick, R. W., Cheuvront, S. N., & Sawka, M. N. (2007). Thermoregulatory Function During the Marathon: *Sports Medicine*, *37*(4), 312-315. https://doi.org/10.2165/00007256-200737040-00010

Kondo, N., Taylor, N. A. S., Shibasaki, M., Aoki, K., & Muhamed, A. M. C. (2009). Thermoregulatory adaptation in humans and its modifying factors. *Global Environmental Research*, 35-41.

Laursen, P. B., Francis, G. T., Abbiss, C. R., Newton, M. J., & Nosaka, K. (2007). Reliability of Time-to-Exhaustion versus Time-Trial Running Tests in Runners. *Medicine & Science in Sports & Exercise*, *39*(8), 1374-1379. https://doi.org/10.1249/mss.0b013e31806010f5

Lei, T.-H., & Wang, F. (2021). Looking ahead of 2021 Tokyo Summer Olympic Games : How Does Humid Heat Affect Endurance Performance? Insight into physiological mechanism and heat-related illness prevention strategies. *Journal of Thermal Biology*, *99*, 102975. https://doi.org/10.1016/j.jtherbio.2021.102975

Mariak, Z., Lewko, J., Luczaj, J., Polocki, B., & White, M. D. (1994). The relationship between directly measured human cerebral and tympanic temperatures during changes in brain temperatures. *European Journal of Applied Physiology and Occupational Physiology*, *69*(6), 545-549. https://doi.org/10.1007/BF00239873

Morán-Navarro, R., Courel-Ibáñez, J., Martínez-Cava, A., Conesa-Ros, E., Sánchez-Pay, A., Mora-Rodriguez, R., & Pallarés, J. G. (2019). Validity of Skin, Oral and Tympanic Temperatures During Exercise in the Heat : Effects of Wind and Sweat. *Annals of Biomedical Engineering*, *47*(1), 317-331.

https://doi.org/10.1007/s10439-018-02115-x
Mündel, T., Bunn, S. J., Hooper, P. L., & Jones, D. A. (2007). The effects of face cooling during hyperthermic exercise in man: Evidence for an integrated thermal, neuroendocrine and behavioural response. *Experimental physiology*, *92*(1), 187-195. https://doi.org/10.1113/expphysiol.2006.034934
Nielsen, B., Hyldig, T., Bidstrup, F., González-Alonso, J., & Christoffersen, G. R. J. (2001). Brain activity and fatigue during prolonged exercise in the heat. *Pflügers Archiv*, *442*(1), 41-48. https://doi.org/10.1007/s004240100515
Notley, S. R., Flouris, A. D., & Kenny, G. P. (2018). On the use of wearable physiological monitors to assess heat strain during occupational heat stress. *Applied Physiology, Nutrition, and Metabolism*, *43*(9), 869-881. https://doi.org/10.1139/apnm-2018-0173
Nybo, L. (2012). Brain temperature and exercise performance : Brain temperature and exercise performance. *Experimental Physiology*, *97*(3), 333-339. https://doi.org/10.1113/expphysiol.2011.062273
Nybo, L., & Nielsen, B. (2001). Hyperthermia and central fatigue during prolonged exercise in humans. *Journal of Applied Physiology*, *91*(3), 1055-1060. https://doi.org/10.1152/jappl.2001.91.3.1055
Nybo, L., Rasmussen, P., & Sawka, M. N. (2014). Performance in the Heat—Physiological Factors of Importance for Hyperthermia-Induced Fatigue. *Comprehensive Physiology*, *4*(2), 657-689. https://doi.org/10.1002/cphy.c130012
Omius. FAQ. https://www.omius.io/pages/faq (accessed March 10th 2024)
Pancrate, T., Gosselin, J., Deshayes, Thomas. A., & Goulet, E. D. B. (2020). Validity and Reliability of the CorTempTM Telemetric Pill during 50 h of Reuse in a Circulating Water Bath. *Journal of Thermal Biology*, *93*, 102737. https://doi.org/10.1016/j.jtherbio.2020.102737
Parton, A. J., Waldron, M., Clifford, T., & Jeffries, O. (2021). Thermo-behavioural responses to orally applied l-menthol exhibit sex-specific differences during exercise in a hot environment. *Physiology & behavior*, *229*, 113250. MEDLINE with Full Text. https://doi.org/10.1016/j.physbeh.2020.113250
Pauw, K. D., Roelands, B., Cheung, S. S., De Geus, B., Rietjens, G., & Meeusen, R. (2013). Guidelines to Classify Subject Groups in Sport-Science Research. *International Journal of Sports Physiology and Performance*, *8*(2), 111-122. https://doi.org/10.1123/ijspp.8.2.111
Ramanathan, N. L. (1964). A new weighting system for mean surface temperature of the human body. *Journal of Applied Physiology*, *19*(3), 531-533. https://doi.org/10.1152/jappl.1964.19.3.531
Schweiker, M., Fuchs, X., Becker, S., Shukuya, M., Dovjak, M., Hawighorst, M., & Kolarik, J. (2017). Challenging the assumptions for thermal sensation scales. *Building Research & Information*, *45*(5), 572-589. https://doi.org/10.1080/09613218.2016.1183185
Shiraki, K., Sagawa, S., Tajima, F., Yokota, A., Hashimoto, M., & Brengelmann, G. L. (1988). Independence of brain and tympanic temperatures in an unanesthetized human. *Journal of Applied Physiology*, *65*(1), 482-486. https://doi.org/10.1152/jappl.1988.65.1.482
Simmons, S. E., Saxby, B. K., McGlone, F. P., & Jones, D. A. (2008). The effect of passive

heating and head cooling on perception, cardiovascular function and cognitive performance in the heat. *European Journal of Applied Physiology*, *104*(2), 271-280. https://doi.org/10.1007/s00421-008-0677-y

Smith, K. R., Woodward, A., Lemke, B., Otto, M., Chang, C. J., Mance, A. A., Balmes, J., & Kjellstrom, T. (2016). The last Summer Olympics? Climate change, health, and work outdoors. *The Lancet*, *388*(10045), 642-644. https://doi.org/10.1016/S0140-6736(16)31335-6

Steketee, J. (1973). Spectral emissivity of skin and pericardium. *Physics in Medicine & Biology,* 18**,** 686–94.

Stevens, C. J., Taylor, L., & Dascombe, B. J. (2017). Cooling During Exercise : An Overlooked Strategy for Enhancing Endurance Performance in the Heat. *Sports Medicine*, *47*(5), 829-841. https://doi.org/10.1007/s40279-016-0625-7

Walters, P., Thom, N., Libby, K., Edgren, S., Azadian, A., Tannous, D., Sorenson, E., & Hunt, B. (2017). The Effect of Intermittent Head Cooling on Aerobic Performance in the Heat. *Journal of Sports Science & Medicine*, *16*(1), 77-83.

Watanuki, S. (1993). Effects of head cooling on cardiovascular and body temperature responses during submaximal exercise. *Annals of Physiological Anthropology*, 12(6), 327-333.

Wendt, D. (2007). Thermoregulation during Exercise in the Heat. *Sports Med*, 14.

Xu, J. L., Gan, Y. H., Zhang, D. C., & Li, X. H. (2005). Microscale heat transfer enhancement using thermal boundary layer redeveloping concept. *International Journal of Heat and Mass Transfer*, *48*(9), 1662-1674. https://doi.org/10.1016/j.ijheatmasstransfer.2004.12.008

Table

Table 1. Physiological variables and urine and blood markers of the participants at their arrival at the laboratory.

Variables	**SH**	**OH**	***p*-value**
Body mass (kg)	73.1 ± 12.4	73.1 ± 12.7	0.963
Urine specific gravity (g/mL)	1.013 ± 0.006	1.013 ± 0.008	0.908
Urine osmolality (mOsmol/kg)	489.3 ± 232.0	503.4 ± 267.3	0.910
Urine color (a.u.)	3.4 ± 1.6	3.2 ± 1.4	0.764
Whole blood osmolality (mOsmol/kg)	298.8 ± 4.1	299.4 ± 6.9	0.810

Values are presented as mean ± SD; a.u. = arbitrary units.

Figure legends

Figure 1. Illustration of the experimental protocol.

Figure 2. Effect of SH and OH on rectal temperature during the 70 min submaximal running effort (A) and the 5-km running TT (B) and mean skin temperature during the 70 min submaximal running effort (C) and the 5-km running TT (D). Results are mean ± SD.

Figure 3. Effect of SH and OH on forehead temperature during the 70 min submaximal running effort. Results are mean ± SD.

Figure 4. Effect of SH and OH on heart rate during the 70 min submaximal running effort (A) and the 5-km TT (B). Results are mean ± SD.

Figure 5. Effect of SH and OH on perceived exertion (A, B), overall thermal comfort (C, D) and forehead thermal comfort (E, F) during the submaximal running effort and 5-km TT. Results are mean ± SD. a.u. = arbitrary unit.

Figure 6. Effect of SH and OH on 5-km running TT performance. Rectangles represent mean results ± SD, whereas lines represent individual times.

Figures

Figure 1.

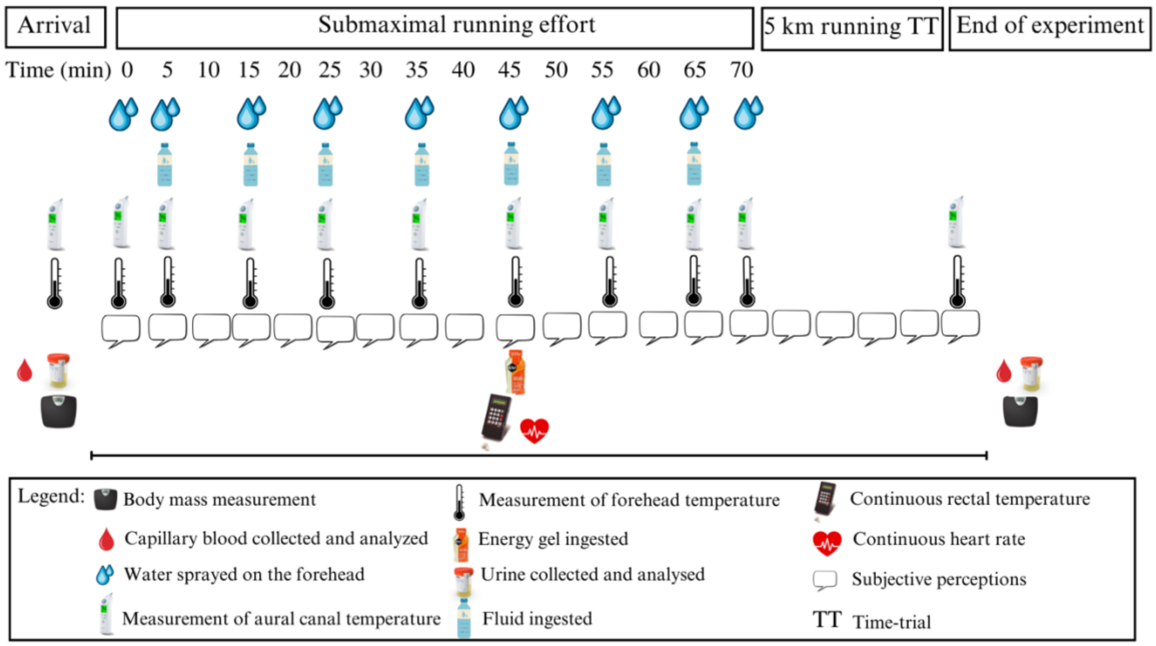


Figure 2.

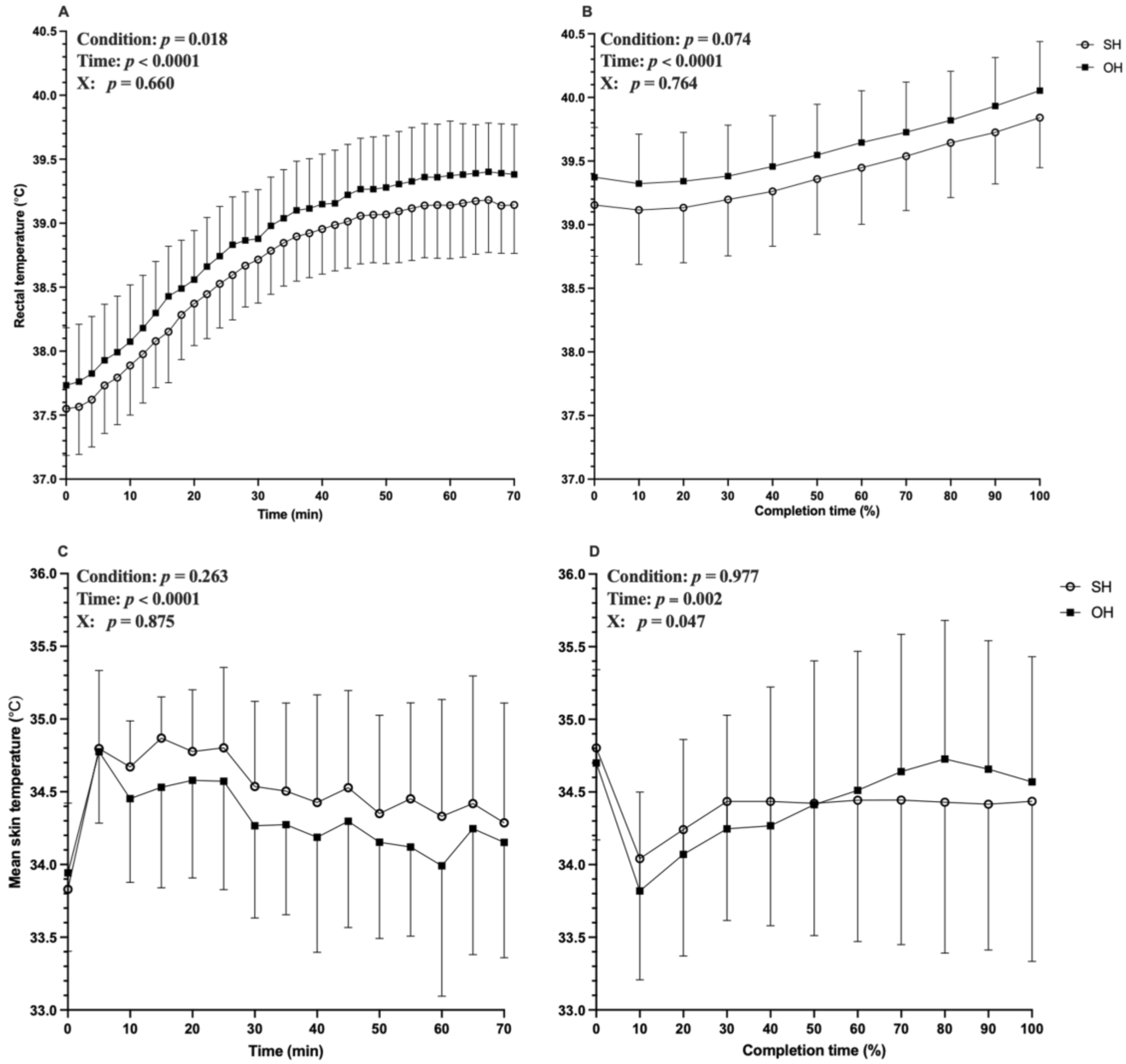

A
Condition: $p = 0.018$
Time: $p < 0.0001$
X: $p = 0.660$
Rectal temperature (°C)
Time (min)
B
Condition: $p = 0.074$
Time: $p < 0.0001$
X: $p = 0.764$
Completion time (%)
SH
OH
C
Condition: $p = 0.263$
Time: $p < 0.0001$
X: $p = 0.875$
Mean skin temperature (°C)
Time (min)
D
Condition: $p = 0.977$
Time: $p = 0.002$
X: $p = 0.047$
Completion time (%)
SH
OH

Figure 3.

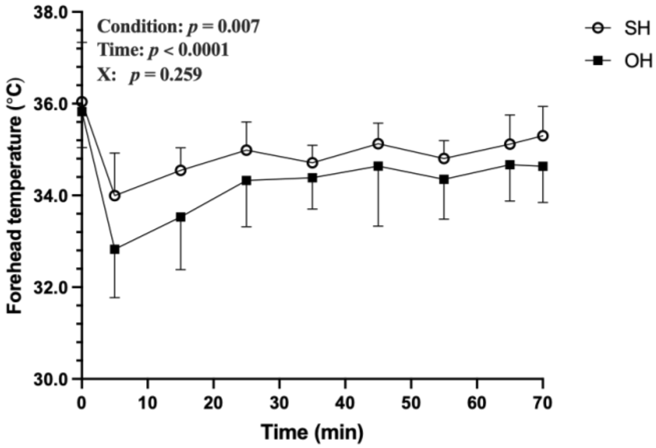


Figure 4.

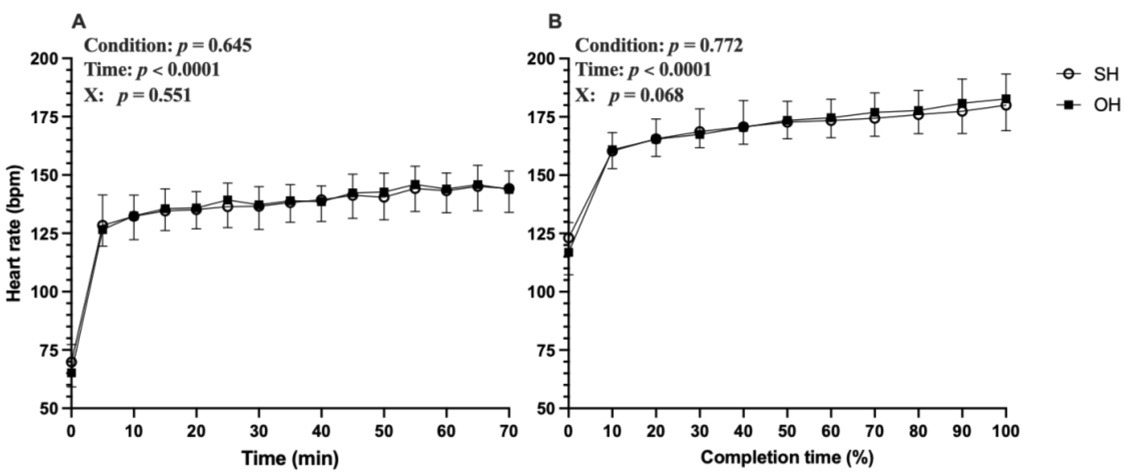
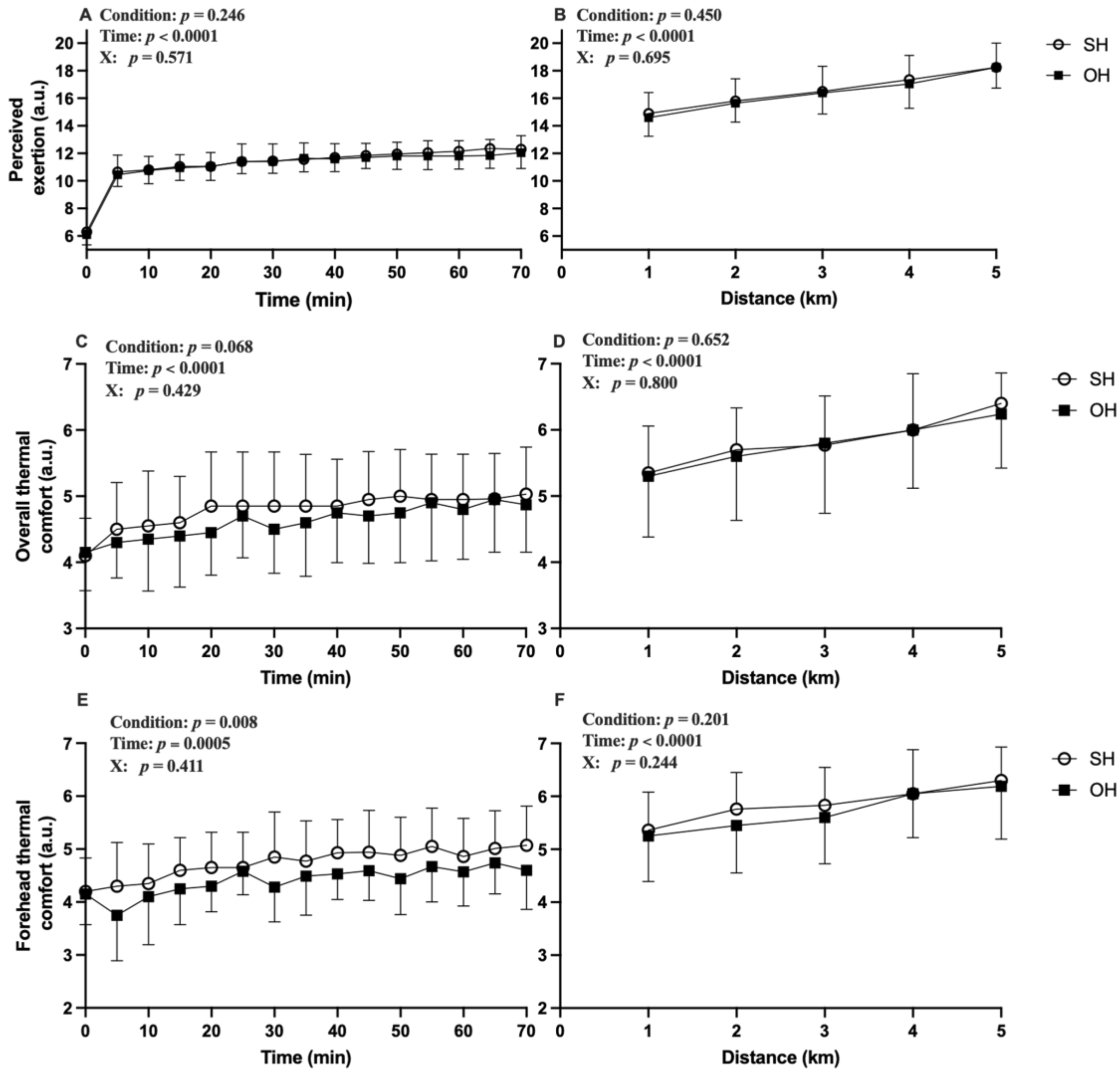
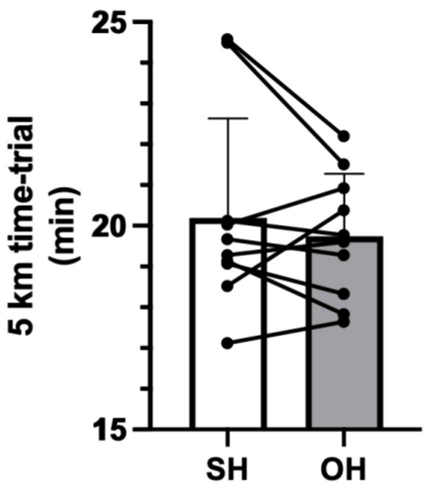


Figure 5.



A Condition: p = 0.246
Time: p < 0.0001
X: p = 0.571
Perceived exertion (a.u.)
Time (min)
B Condition: p = 0.450
Time: p < 0.0001
X: p = 0.695
Distance (km)
SH
OH
C Condition: p = 0.068
Time: p < 0.0001
X: p = 0.429
Overall thermal comfort (a.u.)
Time (min)
D Condition: p = 0.652
Time: p < 0.0001
X: p = 0.800
Distance (km)
SH
OH
E
Condition: p = 0.008
Time: p = 0.0005
X: p = 0.411
Forehead thermal comfort (a.u.)
Time (min)
F
Condition: p = 0.201
Time: p < 0.0001
X: p = 0.244
Distance (km)
SH
OH

Figure 6.



Supplementary material

Figure 1. Omius™ headband (OH) and sham Omius™ headband (SH)