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CONDUCTIVE COOLING OF THE FOREHEAD DURING PHYSICAL ACTIVITY INCREASES COMFORT AND DAMPENS THE MAGNITUDE OF PHYSIOLOGICAL RESPONSES

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ABSTRACT

Carrasco MA, Gonzales JM. Conductive cooling of the forehead during physical activity increases comfort and dampens the magnitude of physiological responses. *JEPonline* 2009; 12(2):9-20. The present study investigated whether conductive cooling of the forehead during exercise could affect core temperature. We also assessed any changes in skin temperature, heart rate, sweat loss, and perceived ratings of fatigue and thermal comfort. Twelve healthy males (age, 23±3 years; HRmax, 197±5 beats per minute) exercised for 20 minutes on a treadmill at 60% of their maximum heart rate at 20°C (42% relative humidity) with cooling (COOL) and without (CON) as a control. Five healthy males (age, 25±4 years; HRmax, 195±5 beats per minute) exercised at 75% of their maximum heart rate with and without cooling at the same ambient temperature and relative humidity. Results from the two studies were compared to see if the cooling effects varied at different exercise intensities. Core temperature was 0.4°C (P<0.05) lower in the COOL treatment than the CON at 75% HRmax and slightly significantly lower at 60% HRmax (by 0.15°C; P=0.08). Conductive forehead cooling resulted in a significant reduction of heart rate at both 60% and 75% HRmax (13 bpm and 22 bpm less, respectively; (P<0.05). Skin temperature in the COOL treatment was significantly lower than the CON at both intensities; by 1.7°C at 60% HRmax and 2.7°C at 75% HRmax (P<0.01). We show here that conductive cooling of the forehead attenuated a rise in core and skin temperature during exercise in a thermal neutral environment. Subjects were more thermally comfortable and less fatigued when conductive cooling was applied.

Keywords: Exercise, Enhancement, Performance, Face-cooling

INTRODUCTION

Heat build up in the body is believed to contribute to fatigue and can prematurely terminate the exercise session (1-3). Studies have shown individuals who exercise in a hot and humid environment perform beneath their maximum capacity. Most commonly, heat buildup can be the result of metabolic heat production associated with vigorous activity or due to heat gain from the environment (2,3). Both may result in an increase in core temperature, with 40°C generally being the core temperature that results in exercise cessation due to fatigue (5).

Besides negatively affecting athletic performance, excessive heat buildup may lead to one or more heat related illnesses if the body is not able to dissipate the heat effectively (6, 14). There are several unique heat related illnesses ranging from moderate, such as cramps, to more severe, such as heat stroke, and may culminate in death (6, 14). Furthermore, less severe heat related illnesses may lead to more severe cases if not diagnosed and treated in a timely manner. Exercising in the heat may also lead to immune depression leaving the individual more susceptible to secondary infections (7).

There are several methods used to address heat build up in the human body, ranging from dry and mist convection (8-12), pre-cooling (13), ice water immersion (14), cooling vests (15-18), and hand cooling via the RTX Core Control unit (19-21). Several of these are impractical in certain situations; dry convection needs a comfortable ambient temperature in order to be effective while mist convection needs relatively low humidity. Precooling is where the subject's core temperature is lowered before exercise in order to create a heat sink in the body. This is generally done by sitting in a cold room for 30-60 minutes before exercise. Ice water immersion is generally a last resort to treat severe heat related illness, such as heat stroke. Sanitation becomes an issue as the individual is immersed in water for 30 minutes or longer (14). Cooling vests have been shown effective in some studies (15, 17, 18), yet in another they have not (16). The hand cooling method is not practical to use during some forms of exercise, as the device weighs twelve pounds and the user must grip the device at all times, leaving him with control of only one hand. The RTX Core Control hand cooling unit has been shown effective in multiple publications by the creators of the device (19- 21).

Though there have been several investigations that examined performance while cooling the face in humans (8-12, 28, 29) there has not been a study conducted on cooling the forehead alone. We wish to investigate whether there is a benefit to cooling the forehead while exercising. Furthermore, previous face cooling studies cooled the face by misting evaporation (9, 11, 12), dry convection (8), or conduction by applying ice packs (28, 29). Each of these methods had a limited amount of success; however, conductive cooling holds promise as it does not rely on evaporation, which may be inhibited by a humid environment. The experiments which employed ice to conductively cool the face had the most success of the three above mentioned cooling methods but there were inadequacies, namely the ice packs were inserted into a cloth tube which covered the entire head, preventing evaporation of perspiration from occurring. The goal of this work is to construct a lightweight and efficient, conductive heat extraction device that targets the forehead for cooling the body. We targeted the forehead for a variety of reasons. In infrared scans of the human body at rest, the forehead and nearby structures are identified to be radiating the most intense heat relative to the rest of the body (4). The relatively thin layer of skin on the forehead will not retain endogenous heat, unlike the insulation effect observed in adipose tissue that surrounds the torso (22). The forehead has the highest concentration of eccrine sweat glands of any body part indicating that is a primary site for endogenous heat exchange (23, 24). As evaporating sweat dissipates heat, areas of the body with high concentrations of sweat glands may contribute largely to thermoregulation. Also, a previous report has shown that targeting the head for cooling by head fanning significantly reduced both brain and oesophageal temperatures (25). The skin of the face has been previously shown to play a disproportionately large

role in core temperature regulation relative to its surface area compared to other areas of the body (26-28). Finally, by targeting the forehead and integrating the unit into, for example, a helmet (which is already worn by the individual), the user has free use of both hands, leading to a greater probability that the unit will be consistently used.

We have set out to construct and test a cooling device which is practical to use during most exercise and effective in cooling the body. Practical to use was defined as having control of all four appendages and a free range of motion while exercising. In this study, we tested the cooling device on twelve test subjects running on treadmills at 60% maximum heart rate (HRmax) and five subjects running at 75% HRmax. Each intensity consisted of two trials; once with cooling and once without. We chose a shorter exercise length in order to gauge our device; most studies with cooling devices have shown a difference with markedly longer exercise times. If our device can effectively extract heat as it is produced by the body, then we will see evidence for this even in short sessions of fixed intensity concerning core and skin temperatures as well as other physiological parameters.

METHODS

Subjects

Twelve healthy males volunteered their services to undergo testing. Each subject was initially screened for major medical problems or prescription medication via a written questionnaire. If the subject was deemed fit according to his medical history, then he signed a consent form indicating his willingness to partake in the study. A subject was deemed fit if he did not have a serious medical condition and if he regularly trained on a treadmill or other ergometer. After the subject was accepted as a potential candidate, his fitness was assessed on a treadmill using a progressive speed test. Briefly, the subject reported to our facility and was attached to a heart rate monitor (Polar Accurex Plus, Polar Electro Oy, Finland). Each subject would walk at 4.8 kilometers per hour (kph) for 5 minutes to warmup and then the speed was increased every 3 minutes by increments of 0.2 kph until the subject reported volitional fatigue. Our criteria for an adequately conditioned subject was if volitional fatigue was reported within 10% of the subjects predicted maximum heart rate. If the subject was adequately conditioned, then he was accepted for the 60% HRmax experiment. The subsequent speed which gave 60% HRmax and 75% HRmax was calculated from this conditioning assessment. Those subjects who had experience running on treadmills at the speed which gave 75% HRmax were selected for both the 60% HRmax and the 75% HRmax trials. Trials were conducted during summer (May-July) and this study was performed according to the Declaration of Helsinki.

Procedures

Testing was carried out using stationary treadmills (Proform Model 400GI, Logan, UT) and the protocol consisted of three visits per test subject. On the first visit, each subject performed a progressive speed test to determine the running speed which would serve to screen subjects according to conditioning levels and give the corresponding speed to run at to achieve 60% HRmax and 75% HRmax. On the next visit, the subject would use the cooling device (COOL) while on the final visit he would not (NC). Half of the subjects were cooled on their second visit while the other half on their third (picked at random). Subjects exercised at two different intensities, at 60% HRmax and at 75% HRmax. Each of these experiments had two treatments per subject, once with the cooling device and once without. For the 60% HRmax experiment, there were a total of 12 test subjects while the 75% HRmax experiment had five subjects. Each experiment was carried out at $20^{\circ}\pm 0.6^{\circ}\text{C}$ and $42^{\circ}\pm 1.8^{\circ}\%$ relative humidity in a temperature controlled environment with central air conditioning and a dehumidifier (75 Pint Dehumidifier, Whirlpool, Benton Harbor, MI, USA).

Subjects were advised to consume similar meals within 24 hours of the exercise session and to abstain from caffeine. On the afternoon of the session, subjects were advised to consume large

amounts of carbohydrates and drink 500 ml water to ensure proper hydration at lunch. Furthermore, subjects were asked to record their diet, fluid intake, and caffeine consumption 24 hours before each session in order to monitor potentially significant variable patterns. Each subject arrived at between 5 and 6 pm having fasted a minimum of four hours. Subjects ran on the same day every week so each subject took three weeks to complete testing. Subjects were given 200 ml of water during the 10 minute acclimation period. This 10 minutes acclimation period allowed for skin temperature to adjust to ambient temperature. Loss of water due to urination was calculated and taken into consideration for the final sweat loss calculation.

The cooling device consisted of tubing which circled the forehead and fluid was circulated through the tubing. The head piece was made out of a material with high thermal conductivity and the total surface area of contact with the forehead was 19.5 cm². The tubing was held in place by elastic straps and worn for the duration of the exercise session plus the preceding 10 minutes. Due to the high thermal conductivity of the head piece alone, subjects did not wear the device sans fluid for the negative control.

Each subject ran at 60% (or 75%) HR max for 20 minutes during Visits 2 and 3. Six of the subjects used the cooling device on Visit 2 while the remaining 6 used it on Visit 3. Subjects were randomly chosen to use the device on Visit 2 and the remaining subjects were selected to use it on Visit 3. Those subjects who used the cooling device on Visit 2 did not use it during Visit 3, with the order reversed for those subjects who use the cooling device on Visit 3. The speed used for each test subject was determined from his first visit and this was used for visits 2 and 3. Subjects would warm up by walking at 3.0 kph for 5 minutes then the trial would begin by increasing the speed to either 60% or 75% at the end of the warmup.

Measurements were taken every 10 minutes. Skin temperature sensors (Vernier, Beaverton, OR, USA) were attached at the forearm, nape of the neck, and forehead (1.5 cm away from the cooling device headpiece) using medical tape (3M Healthcare, St. Paul, MN, USA). A data logger (Labquest, Vernier, Beaverton, OR, USA) was used to collect data from the skin temperature sensors. Core temperature was measured via a digital tympanic thermometer (Braun Thermoscan PRO 4000, South Boston, MA, USA) as an average of two readings. Ratings of perceived exertion were assessed using the 15-point Borg scale from 6-20 with 7 being very, very easy and 19 being very, very hard. Thermal comfort was assessed using a 10-point scale from 0-10 with 0 being the coldest the subject has ever been, 5 being thermal neutral, and 10 being the hottest the subject has ever been (31).

Subjects were weighed (Omron Scale HBF-400, Kyoto, JPN) down to 0.1 kg partially nude before and after each session in order to determine water loss. After the run, each subject was allowed to dry off via towel drying and convection for a period of 10 minutes. Weight was then measured and water loss was determined as the difference between pre-run and post-run weights. Ambient temperature and relative humidity were measured during each run.

Statistical Analyses

Data were tested for approximation to normal distribution. All data, except sweat loss, were analyzed using a two-way (time x trial) analysis of variance (ANOVA) for repeated measure using the Matlab R2008b software (The Mathworks, Inc, Natick, MA, USA). Values from ANOVA were assessed for sphericity and corrected using the Huynh-Feldt method if necessary. Following a significant *F* test, pairwise comparisons were identified using Tukey's honestly significant difference (HSD) *post hoc* procedure. Microsoft Excel 2007 (Redmond, WA, USA) was used to perform student's paired *t*-tests for all the data at paired time points, including sweat loss. Data are reported as means±S.D. and analyses performed on n=12 for the 60% HRmax study and n=5 for the 75% HRmax study.

RESULTS

Subject Information

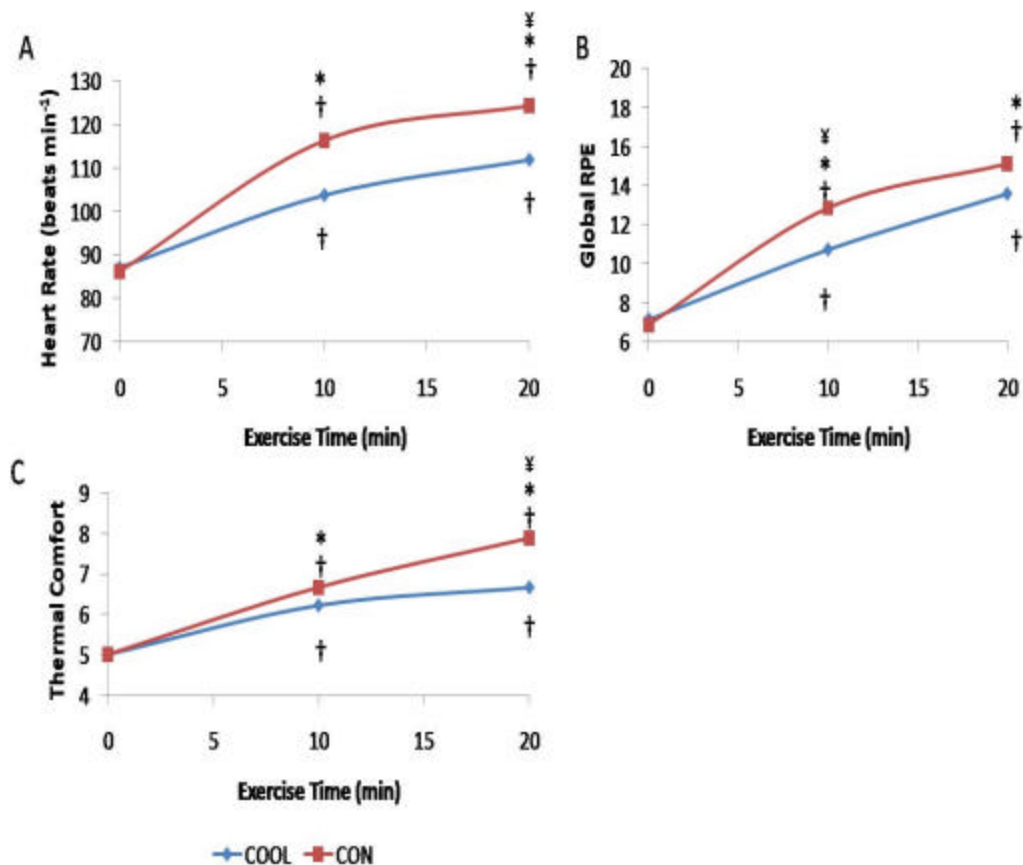
The subjects physical characteristics were as follows for the 60% HRmax study (means±S.D.): age, 23±3 years; body mass, 79 ±10 kg; height, 174±8 cm; and HRmax; 197±5 beats min⁻¹. The average speed which corresponded to 60% HRmax was 7.1±0.6 kph.

For the 75% HRmax study, five volunteers were accepted from the original pool of twelve, as described in Methods. Physical characteristics are as follows: age, 25±4 years; body mass, 79±15 kg; height, 173±7 cm; and HRmax; 195±5 beats min⁻¹. The average speed which corresponded to 75% HRmax was 8.4±0.9 kph.

60% HRmax

For the 60% HRmax experiment, heart rate was significantly lower in the COOL treatment at both 10 and 20 minutes ($P<0.05$, Fig. 1A) than the CON, though the speed at which the subject ran remained constant between treatments. At the end of the exercise session, the CON treatment had a HR ~13 bpm higher than the COOL treatment. Furthermore, both treatments resulted in a significantly higher heart rate at 10 and 20 minutes than baseline levels ($P<0.05$). Core temperature rose slightly more in the CON treatment but this was not significant at the 10 minute time point ($P<0.08$, Fig. 2A). Core temperature decreased slightly in the COOL treatment, though this was not significant ($P>0.05$). The difference in temperature between COOL and CON was significant at 10 minutes ($P<0.05$) but not at 20 minutes. Mean skin temperature (average of three sites) was significantly higher in the CON treatment at all time points (0, 10, and 20 minutes; $P<0.01$, Fig. 2B).

At all time points, mean skin temperature was over 1.0°C higher in the CON. In the CON, mean skin temperatures did not increase significantly above baseline values where in the COOL, they decreased significantly at the conclusion of the exercise session ($P<0.05$). Global RPE (Borg scale) increased significantly for both treatments relative to baseline levels at 10 and 20 minutes ($P<0.001$, Fig. 1B). However, values for COOL were significantly lower than CON with values reaching 13.6±1.5 and 15.2±1.6, respectively ($P<0.01$). Ratings of thermal comfort increased significantly for both treatments relative to baseline ($P<0.001$, Fig. 1C). Values were significantly higher for the CON group than the COOL, with values reaching 7.9±1.1 and 6.7±0.9, respectively ($P<0.001$). Sweat loss was assessed as the change in body mass before and after the exercise session. The COOL resulted in



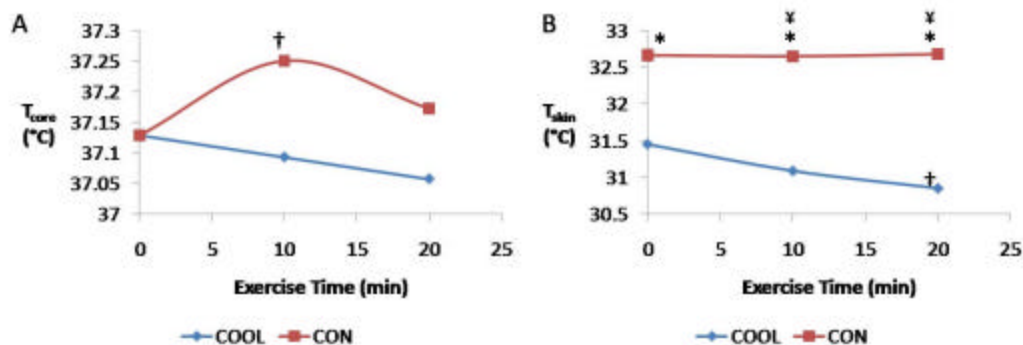


Figure 2. Core temperature (T_{core};A), Mean skin temperature of three sites (T_{skin}; B) during exercise for CON and COOL at 60% HRmax. *Denotes significant difference between trials (t-test CON vs. COOL); † denotes significant difference within a trial (t-test vs. baseline); ‡ denotes significant difference between trials (ANOVA CON vs. COOL).

Figure 3A). The COOL treatment had a significantly lower increase in heart rate than the CON, with heart rate reaching 123±4 bpm and 145±12 bpm, respectively (P<0.05). Core temperature increased significantly compared to baseline in the COOL treatment at 10 minutes (P<0.05) but not at 20 minutes (Fig. 4A). For the CON treatment, core temperature increased significantly compared to baseline at both 10 and 20 minutes (P<0.01). The COOL treatment had significantly lower temperatures at 20 minutes than the CON (P<0.01) with a difference of 0.4°C. Mean skin temperatures did not increase significantly in the COOL treatment but did so in the CON treatment at 20 minutes (P<0.05, Fig. 4B). The COOL treatment had significantly lower skin temperatures than the CON at each of the time points (0, 10, and 20 minutes; P<0.01). At the end of the exercise session, the CON treatment had a mean skin temperature of 35.3±0.9°C while the COOL had a reading of 32.6±1.4°C. Both treatments resulted in a significant increase in Global RPE relative to baseline values (P<0.01, Fig. 3B). The COOL treatment had lower RPE values compared to the CON with values reaching 13.9±1.3 and 16.9±1.6, respectively (P<0.01). The COOL treatment resulted in a significant increase in subjective thermal comfort compared to baseline at 10 and 20 minutes (P<0.5) whereas the COOL treatment increased significantly only at the 20 minute time point (P<0.05, Fig. 3C). The CON treatment had significantly higher values than the COOL with values reaching 8.1±0.8 and 6.0±0.6, respectively (P<0.01). Sweat loss was significantly higher in the CON treatment than the COOL, 730±80 ml and 500±100 ml, respectively (P<0.05). Both treatments resulted in a significant change in body mass.

DISCUSSION

Heat buildup during exercise can lead to premature termination of the session if the body's natural cooling mechanism cannot effectively dissipate the heat. Reports have shown that individuals are able to exercise longer if they are cooled by some external mechanism (8-12, 18, 19, 21). Furthermore, less stress hormones are secreted (9, 11, 12), which may result in less soreness the following day. Each of the various parameters we assessed showed a significant difference between the COOL and CON treatment at either 60% or 75% HRmax or both.

Heart Rate Response

Each subject ran at the same speed in the 60% HRmax study for both treatments; COOL and CON. This is also true for the 75% HRmax study. As such, the CON run serves as the true gauge of percent HRmax while the COOL treatment is potentially variable. If the cooling device tested here can

significantly less sweat loss than the CON, 160 ml less sweat (P<0.01). Both treatments resulted in a significant change in body mass post exercise compared to pre-exercise.

75% HRmax

Heart rate increased significantly above the baseline in both treatments (P<0.01,

efficiently extract heat as it is produced by the body during exercise, then the heart rate during the COOL treatment should be lower than for the CON. Heart rate was significantly lower in the COOL treatment compared to the CON, 13 bpm less in the 60% HR max and 22 bpm less in the 75% HR max. This reduction is in agreement with another study (11) that found that cooling the face via misting convection causes a reduction in heart rate of 5 bpm during cycling. Also, Grahn et al found that hand cooling causes a lower increase in heart rate while subjects exercised on a treadmill in a hot environment (19). In a cooling vest study, there was no significant difference in heart rate between the cooling vest treatment versus the control (18).

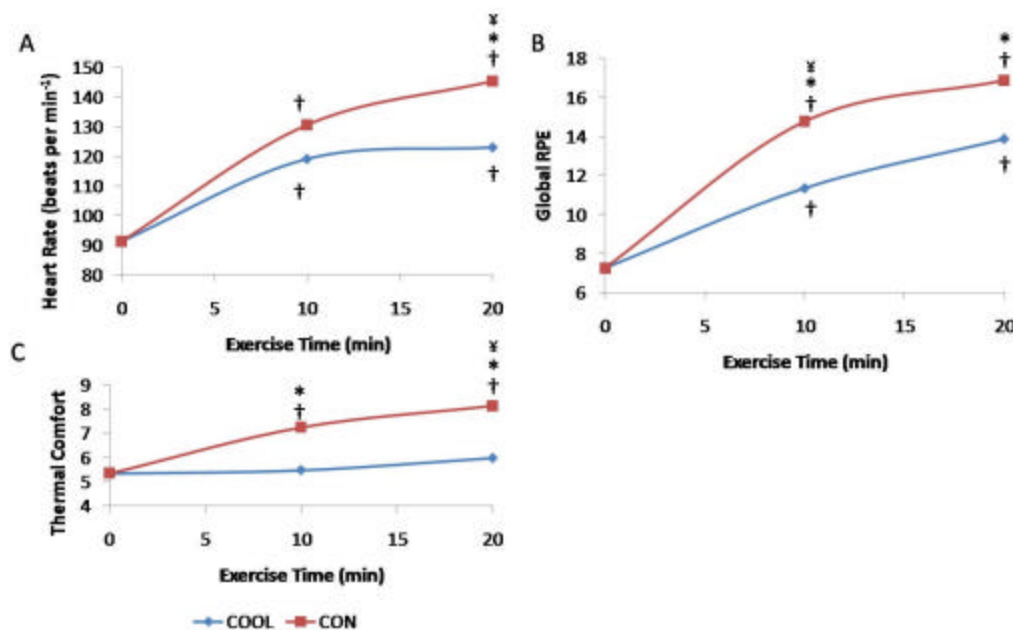


Figure 3. Heart rate and perceived ratings response during 75% HRmax. A) Heart rate response during exercise for CON and COOL. B) Global RPE during exercise for CON and COOL. C) Subjective thermal comfort during exercise for CON and COOL. *Denotes significant difference between trials (t-test CON vs. COOL); † denotes significant difference within a trial (t-test vs. baseline); ‡ denotes significant difference between trials (ANOVA CON vs. COOL).

Heat buildup during exercise is believed to contribute to cardiac drift when exercising at a fixed load (23). When heat is efficiently extracted from the body as it is produced, then cardiac drift is dampened, which was observed in this study. Heart rate increases in response to heat buildup in order to increase cardiac output to deal with the excess heat. By increasing cardiac output, the body can shunt more blood to the surface of the skin to aid in heat dissipation. The heart rate difference between treatments in our study was larger than the two above mentioned studies that had a difference between cooling and control treatments, which may indicate a greater efficiency of heat extraction.

Core Temperature Response

Core temperature was significantly less in the COOL treatment at 75% HR max (0.4°C). This reduction in core temperature is also seen in other studies with cooling devices (15, 18, 19). In a study by Webster et al concerning cooling vests and exercising in a hot environment, there was a significant reduction in core temperature (18). In another cooling vest study where subjects wore the cooling vests one hour prior to exercise, their core temperatures were 0.5°C cooler (15). Grahn et al investigated the effects of the hand cooling unit in subjects exercising in a hot environment and found that using the device resulted in a 0.3°C reduction in core temperature at the end of 20 minutes (19). Their experiment was allowed to continue for a longer amount of time compared to our study but we make the comparison at 20 minutes as this corresponds to the exercise session length in our study.

However, the limitation to this comparison is that our subjects exercised at a moderate ambient temperature whereas subjects in the other studies exercised in hot environments.

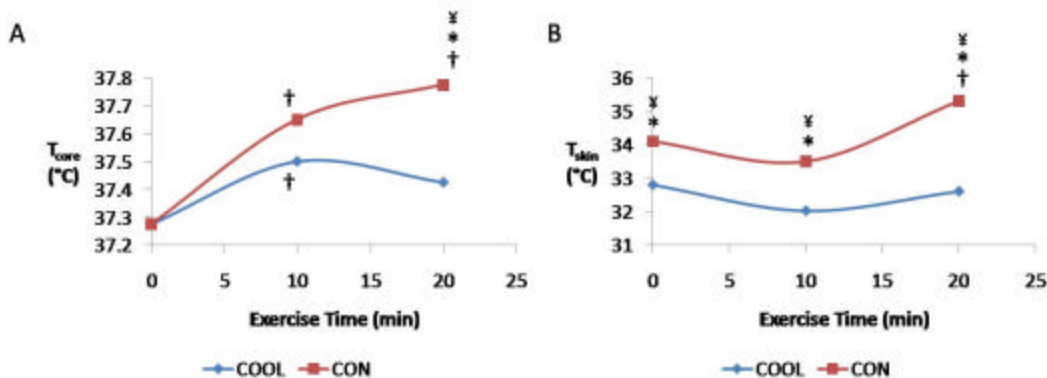


Figure 4. Core temperature (T_{core} ; A), Mean skin temperature of three sites (T_{skin} ; B) during exercise for CON and COOL at 60% HRmax. *Denotes significant difference between trials (t-test CON vs. COOL); † denotes significant difference within a trial (t-test vs. baseline); ‡ denotes significant difference between trials (ANOVA CON vs. COOL).

The effects of face cooling on core temperature have been investigated numerous times with mixed results (8-12). In a study that cooled the face by misting convection, there was no significant difference between the two treatments (11). These studies misted the entire face with cool mist. In contrast, our device targeted only the forehead for conductive cooling.

Misting convection relies on a humidity gradient to effectively evaporate the water mist, thus carrying heat from the skin into the environment. When humidity is higher, then evaporation does not proceed efficiently; as is the case in studies where subjects are exerting themselves to the point of perspiring. Perspiration adds moisture to the immediate environment, thus lowering the humidity gradient and rate of evaporation. Consequently, cooling is compromised.

In another face cooling study, subjects were cooled by conduction by placing ice packs in an elastic cloth tube and this covered the whole head (28, 29). There was a significant difference between the cooled and control treatment of about 0.5°C and subjects exercised at elevated ambient temperatures. These studies cooled the entire face by conduction with ice packs inserted into a cloth tube which covered the subject's head. By covering the entire head, the subject's natural cooling mechanism, evaporation of perspiration, was negated on the head region. If evaporation was not inhibited, then it would be reasonable to expect a greater cooling benefit in these studies than what was found.

Core temperature is strictly regulated to a tenth of a degree Celsius so the short running time and moderate ambient temperature in our experiment prevented a large increase in core temperature. The differences in core temperature most likely would have been larger if the exercise session was lengthened and if the ambient temperature was increased, as in the case of the hand cooling unit. However, there were significant and slightly significant differences between the COOL and CON treatments in our study, indicating our device was able to attenuate a rise in core temperature by extracting heat as it was produced. The effect at 75% HRmax was comparable to the cooling effects of other devices (15, 18, 19), yet their subjects exercised for longer periods of time and often in elevated ambient temperatures.

Skin Temperature Response

Mean skin temperature was significantly less in the COOL treatment than the CON, by 1.8°C at 60% HRmax and 2.7°C at 75% HRmax. This included the skin temperatures at three sites, the forearm,

the nape of the neck, and the forehead (1.5 cm away from the head piece to prevent detecting the local cooling effect). Webster et al. (18) found that a cooling vest could significantly lower skin temperature while running (assessed bicep and abdominal skin temperatures). In face cooling studies, Mundel et al did not detect a significant difference in skin temperature (assessed at the calf, hand, and lower back) while using misting convection to cool the face (11). However, in a study where the head was cooled by conduction (28), there was a significant reduction in mean skin temperature by over 1°C (mean skin temperature assessed at the forehead, hand, lower back, and calf).

When the body is heat stressed, more blood is circulated to the periphery in order to carry heat to the surface where it can be dissipated by evaporation, conduction, and convection. As such, one can measure the increase in heat to the skin surface to indirectly show an increase in thermal load. There is not a correlation between skin and core temperatures so the increase in skin temperature cannot directly quantitate thermal load. If heat is efficiently extracted from the body as it is produced by the cooling device, then one would expect to see a significant reduction in skin temperature increase relative to the control treatment, which was observed in the present study. Our magnitude of skin temperature cooling was larger than in other studies, even though their exercise sessions were more intense and of a longer duration. Such a difference can be explained by the efficiency of our device to extract heat from the body and the location targeted for cooling; the forehead. Our device relies on conductive cooling to extract heat from an area of the body previously shown to play a disproportionately large role in core temperature regulation relative to its surface area.

Rate of Perceived Exertion

There was a significant difference in perceived exertion between the COOL and CON treatments at both 60% and 75% HR max, 0.9 and 3.0 units lower, respectively. We used the Borg scale, which is a 15 point scale widely used by sports physiologists and allows for the subjects perceptual feedback (30). Unlike assessing physiological parameters, the Borg scale allows the subject to describe how hard he is working according to a numeric scale. Mundel et al found that face cooling by misting convection resulted in a less strenuous exercise session but only at the 40 minute time point (11).

In our experiments, we found a similar trend between intensities. Cooling in the 75% HR max resulted in drastically greater differences in perceived exertion compared to cooling in the 60% HR max. Core temperature was attenuated to a greater extent in the 75% HR max trial, which resulted in a lessened sense of fatigue. Simmons et al found there was a significant correlation between an increase in core temperature and perceived exertion (28). Our device resulted in significant differences in skin temperatures at both 60% and 75% HR max and a significant difference in core temperature at 75% HR max. Combined with the lower ratings of perceived exertion, we find that our data matches the correlation between core temperature and rating of perceived exertion (28). Furthermore, our findings show that the greater the intensity of exercise, the greater the perceived benefits of our cooling device concerning fatigue.

Relative Thermal Comfort

Subject thermal comfort was significantly lower in the COOL treatments compared to the CON in both the 60% and 75% HR max studies, 1.3 and 2.1 units lower, respectively. Thermal comfort is assessed on a ten point scale and relies on the subjects' perceived comfort (31). Mundel et al. found that using misting convection to cool the face results in a significantly more thermal comfortable exercise session (11). Our findings were in agreement with Mundel et al that cooling the face does result in a significantly more thermal comfortable exercise session. When the differences are converted to percentages, our cooling device resulted in a workout session at 75% HR max that was 21% more comfortable than the CON. If heat is extracted as it is produced, then the subject will feel

more comfortable from a thermal standpoint, which is what we observed here. In contrast to the findings by Mundel et al, our findings showed that cooling the forehead did result in a lower core and mean skin temperatures, indicating that the body was being cooled by targeting the forehead for cooling.

Sweat Loss

Sweat loss for the COOL treatment was significantly less than the CON in both the 60% and 75% HRmax studies, 160 ml and 230 ml less, respectively. Webster et al found that wearing a cooling vest during exercise at elevated temperature results in less sweat loss than without the vest (18). Cooling the face via conduction with ice packs results in significantly less sweat lost during exercise at elevated temperature (28). Among other factors, sweat rate is correlated to core temperature, with higher core temperatures resulting in a greater sweat rate. By cooling the body with an external device and thus attenuating a rise in core temperature, the sweat rate is decreased and the likelihood of dehydration decreases. Though the sweat glands have a capacity to reabsorb ions from sweat, high sweat rates decrease the reabsorption of ions and this further contributes to a greater chance of dehydration (23). By cooling the core and lowering the sweat rate, it is possible to reduce the risk of dehydration by preserving fluid and electrolytes.

CONCLUSIONS

The cooling device tested here can effectively extract heat from the body as it is produced during exercise. Our device shows promise to cool individuals and perhaps increases their performance during exercise bouts. The natural cooling mechanism of the body and ensuing cardiorespiratory responses require energy in order to deal with the increased thermal load. By using an external device that can effectively extract heat, the magnitude of thermal response by the body is lessened. This may mean that less energy is required to perform the exercise session but more experiments would be necessary to confirm. Furthermore, our study gave evidence that the greater the thermal load caused by more intense exercise, the greater the derived benefit of using our heat extraction device.

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