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original research

Cooling the Neck Region During Exercise in the Heat

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Context: Cooling the neck region can improve the ability to exercise in a hot environment. It might improve performance by dampening the perceived level of thermal strain, allowing individuals to override inhibitory signals.

Objective: To investigate whether the enhanced ability to exercise in a hot environment observed when cooling the neck region occurs because of dampening the perceived level of thermal strain experienced and the subsequent overriding of inhibitory signals.

Design: Crossover study.

Setting: Walk-in environmental chamber.

Patients or Other Participants: Eight endurance-trained, nonacclimated men (age = 26 ± 2 years, height = 1.79 ± 0.04 m, mass = 77.0 ± 6.2 kg, maximal oxygen uptake [$\dot{V}O_{2max}$] = 56.2 ± 9.2 mL·kg^{-1}·min^{-1}) participated.

Intervention(s): Participants completed 4 running tests at approximately 70% $\dot{V}O_{2max}$ to volitional exhaustion: 2 familiarization trials followed by 2 experimental trials (cooling collar [CC] and no collar [NC]). Trials were separated by 7 days. Familiarization and NC trials were performed without a collar and used to assess the test variability.

Main Outcome Measure(s): Time to volitional exhaustion, heart rate, rectal temperature, neck skin temperature, rating of perceived exertion, thermal sensation, and feeling scale (pleasure/displeasure) were measured.

Results: Time to volitional exhaustion was increased by 13.5% ± 3.8% (CC = 43.15 ± 12.82 minutes, NC = 38.20 ± 11.70 minutes; t_7 = 9.923, $P < .001$) with the CC, which reduced mean neck skin temperature throughout the test ($P < .001$). Participants terminated exercise at identical levels of perceived exertion, thermal sensation, and feeling scale, but the CC enabled participants to tolerate higher rectal temperatures (CC = 39.61°C ± 0.45°C, NC = 39.18°C ± 0.7°C; t_7 = −3.217, P = .02) and heart rates (CC = 181 ± 6 beats/min, NC = 178 ± 9 beats/min; t_7 = −2.664, P = .03) at the point of termination.

Conclusions: Cooling the neck increased the time taken to reach volitional exhaustion by dampening the perceived levels of thermal strain.

Key Words: hyperthermia, thermoregulation, treadmill, exhaustion, fatigue

Key Points

- Cooling the neck region dampened the perceived level of thermal strain, enabling participants to increase the time to reach volitional exhaustion.
- Dampening of the perceived level of thermal strain delayed the point of voluntary termination of exercise.
- When their neck regions were cooled, participants tolerated higher rectal temperatures and heart rates before they voluntarily terminated exercise than when their neck regions were not cooled.
- Because of the dampened perception of thermal state, effective monitoring and briefing procedures are required to ensure the individual's safety during exercise performed in a hot environment with a cooling device applied.

Researchers have demonstrated that time-trial performance is impaired by approximately 10% when environmental conditions are hot (30°C) rather than temperate (14°C)[1] and that cooling the neck region via a cooling collar (CC) can attenuate this reduction, improving exercise performance in a hot environment by approximately 6%.[2] Although the beneficial effect of a CC on performance was clearly established in these studies, the finite nature of the test limited the extent to which the improvement could be explained. The performance of the participants was restricted by the closed method of assessment (ie, a design with a fixed or known endpoint). Therefore, it was not possible to test the hypothesis that the improved performance was due to an enhanced ability to tolerate thermal strain because of a dampening of thermal feedback.

The time taken to reach volitional exhaustion also is impaired in hot compared with temperate conditions.[3] Although numerous investigators have provided valuable data to help explain the reduced ability to sustain exercise in hot conditions, the reasons still are not understood fully. The impairment often is attributed to the development of hyperthermia because, in laboratory-based investigations, exercise is consistently terminated voluntarily at core temperatures of approximately 40°C, regardless of the initial temperature, acclimation status, or hydration levels of participants.[4,5] Researchers have proposed that exercise termination at such temperatures prevents the body from reaching temperatures that would lead to the onset of potentially fatal heat illness.[5,6] Although consistency in the core temperatures is observed at voluntary exercise termination in laboratory tests, core temperatures in excess of 40°C have been recorded after athletic competition.[7] The ability to exceed temperatures of approximately 40°C during exercise demonstrates that the mechanisms that limit exercise in a hot environment can be overridden and that temperatures in excess of 40°C can be tolerated during exercise in sufficiently motivated athletes.

Cooling the body before exercise has regularly been shown to increase the time taken to reach volitional exhaustion and to improve exercise performance in hot conditions.[8,9] The reason for the improvement often is attributed to a reduction in core temperature at any comparative time point during the exercise bout, but improvements have occurred in the absence of core-temperature reductions after decreases in skin temperature.[8,10] Cooling the neck region via a practical neck CC can enhance exercise performance in hot conditions without altering the physiologic response to the exercise bout.[2] The head, neck, and face are regions of high allesthesial thermosensitivity,[11] and cooling the neck has been shown to more effectively alleviate heat strain than cooling the same surface area of the trunk.[12] Investigators have proposed that the neck might be an optimal site to cool because of its close proximity to the thermoregulation center,[12,13] which is located at the base of the brain and receives afferent signals regarding the thermal state of the body from many deep and peripheral thermoreceptors.[14] Researchers have suggested that self-paced exercise in a hot environment is regulated by integrated feedback from many physiologic and perceptual systems (commonly referred to as the *central governor theory*).[15,16] Cooling the neck region might enhance exercise performance by providing a false signal of the body's thermal state, allowing the selection of a faster, "unnatural" pace. If cooling the neck region provides a false signal that allows performance to be improved, it also would prolong exercise in a hot environment by masking the extent of the thermal strain experienced, allowing the participant to tolerate a higher core temperature and level of thermal strain by overriding the thermal signals governing the termination of exercise. This has obvious potential performance-enhancing implications; however, it also might pose a threat to the health of the participant. If the extent of the thermal strain experienced is masked heavily, the athlete might experience potentially dangerous body temperatures that put him or her at risk for heat illness, so caution might be required when using cooling during exercise in a hot environment. Therefore, the aim of our study was to investigate whether the enhanced ability to exercise in a hot environment observed when cooling the neck region occurs as a result of dampening the perceived level of thermal strain experienced and the subsequent overriding of inhibitory signals.

METHODS

Participants

Eight endurance-trained, nonacclimated men (age = 26 ± 2 years, height = 1.79 ± 0.04 m, mass = 77.0 ± 6.2 kg, maximal oxygen uptake [$\dot{V}O_{2max}$] = 56.2 ± 9.2 $mL \cdot kg^{-1} \cdot min^{-1}$) volunteered for the study. Participants were recruited from regional running and triathlon clubs. Power analysis was not conducted for sample size. Before the trials, participants completed a health screening. This screening procedure was repeated before each laboratory visit to ensure that the health status of each participant had not changed. All participants gave their written informed consent, and the study was approved by the Ethical Advisory Committee of Nottingham Trent University.

Experimental Procedures

Before the trials, participants completed an incremental motorized treadmill test to determine $\dot{V}O_{2max}$.[17] After the preliminary test, participants reported to the laboratory at the same time of day ± 30 minutes on 4 occasions with trials separated by 7 days. Participants abstained from consuming alcohol and caffeine and completed a food record for the 24-hour period before the initial trial. They adopted the same diet and abstained from strenuous exercise for 24 hours before each subsequent trial. Participants arrived at the laboratory approximately 30 minutes before the commencement of the trial and equal to or more than 4 hours postprandial.

All trials were conducted in hot ambient conditions (32.2°C ± 0.2°C, 53% ± 2% relative humidity) in a walk-in environmental chamber (model WIR52-20HS; Design Environmental Ltd, Gwent, United Kingdom). During all 4 visits to the laboratory, participants completed an 8-minute standardized warm-up followed by a treadmill test to exhaustion at a speed set to elicit 70% of $\dot{V}O_{2max}$. The 8-minute standardized warm-up consisted of 2 minutes at 50% $\dot{V}O_{2max}$ (8.6 ± 1.3 $km \cdot h^{-1}$), 1 minute at 60% $\dot{V}O_{2max}$ (10.1 ± 1.6 $km \cdot h^{-1}$), 1 minute at 70% $\dot{V}O_{2max}$ (11.9 ± 1.8 $km \cdot h^{-1}$), 1 minute at 50% $\dot{V}O_{2max}$, and 3 minutes of individually selected static stretching. The warm-up bout was included because such a practice precedes most sporting events.[18] The first 2 trials were no-collar (NC) trials and formed 2 familiarization trials (FAM1 and FAM2). During the other 2 trials, participants ran wearing a neck CC (1 trial) or ran with NC (1 trial). The order of the neck CC trial and third NC trial was randomized and counterbalanced. The CC was applied after the 8-minute warm-up period.

Physiologic and Perceptual Variables

On arrival at the laboratory, nude body mass was recorded. A rectal probe (model REC-U-VL-0; Grant Instruments [Cambridge] Ltd, Cambridgeshire, United Kingdom) was self-inserted approximately 10 cm past the anal sphincter, and a heart rate (HR) monitor (model RS400; Polar Electro Oy, Kempele, Finland) was attached before the participant entered the walk-in environmental chamber. During the final 2 visits (CC and third NC trials), 4 skin thermistors (model EUS-U-VL-3; Grant Instruments [Cambridge] Ltd) were attached evenly across the posterior aspect of the neck with transparent dressing (Tegaderm; 3M, St Paul, MN) and waterproof tape (Transpore; 3M). Heart rate, rectal temperature, mean neck skin temperature, rating of perceived exertion,[19] thermal sensation (TS),[20] TS of the neck region (TS_{neck}), and feeling scale[21] were recorded at 5-minute intervals and at the point of exercise termination. Mean neck skin temperature was calculated as the mean temperature of the 4 skin thermistors. The TS was rated with a 9-point scale that ranged from 0 (*unbearably cold*) to 8 (*unbearably hot*), with 4 (*comfortable*) serving as the neutral point.[20] Participants were instructed to differentiate between whole-body TS and TS_{neck} during the final 2 trials. The feeling scale assessed levels of pleasure and displeasure using an 11-point scale that ranged from −5 (*very bad*) to 5 (*very good*), with 0 (*neutral*) serving as the midpoint. Time to exhaustion was recorded in all 4 trials. After the completion of each trial, participants towel dried and

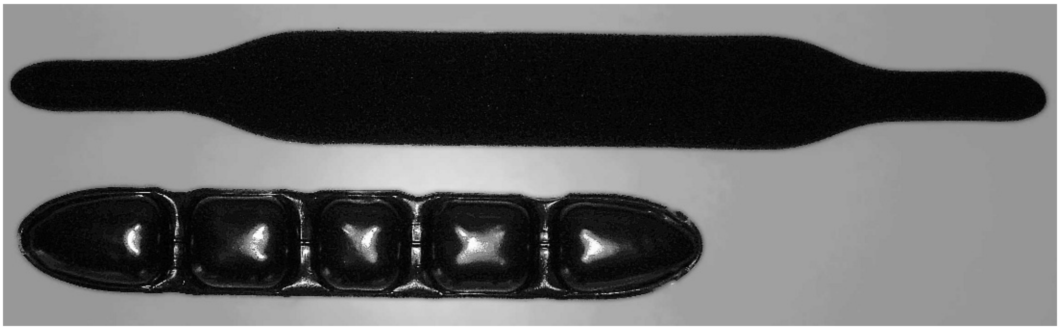

Figure 1. The cooling collar (Black Ice LLC, Lakeland, TN).

recorded a postexercise nude body mass from which we calculated sweat loss and percentage body mass loss, taking into account voluntary fluid consumption.

Cooling Collar

We used a modified commercially available CC (model CCX; Black Ice LLC, Lakeland, TN; Figure 1). The cooling section of the modified CC was made from a thin plastic casing consisting of 5 compartments that were drained of the Black Ice cooling reagent and filled with approximately 120 g of gel refrigerant (BDH Laboratory Supplies, Poole, United Kingdom). Through in-house pilot work, we established that the gel refrigerant provided the greatest magnitude of cooling without resulting in tissue damage. The cooling section of the collar was held in place by a 600-mm neoprene wrap secured with hook-and-loop fastenings at the anterior aspect of the neck. The dimensions of the cooling section of the collar were 375 mm (length) × 60 mm (width) × 15 mm (depth), and it weighed 155 g at room temperature. Before the neck CC trials, the collar was placed in a freezer at −80°C for 24 to 28 hours. Before application, it was placed in ambient conditions for 10 minutes, and then it was cleared of any surface frost. Participants were allowed to drink chilled water (7.1°C ± 2.5°C) ad libitum throughout the trials and were informed that the available volume was unlimited. The data from the 3 trials conducted without the CC intervention (FAM1, FAM2, NC) were used to assess the individual and mean variabilities in exercise time.

Statistical Analyses

Data are presented as means ± SDs. Data for trial variability, time to volitional exhaustion, sweat loss, and fluid consumption in the CC and NC trials were analyzed using 1-tailed paired *t* tests. Two-way analyses of variance (ANOVAs) with repeated measures were conducted for HR, rectal temperature, mean neck skin temperature, and perceptual data. Because capacity times were different in the 2 experimental trials, several comparisons were made. All participants completed at least 20 minutes; therefore, these data were compared using ANOVAs. Data at fatigue were compared with *t* tests. When we found a significant *t* or *F* value, we conducted Tukey honestly significant difference tests to identify pairwise differences. Bonferroni adjustments for multiple comparisons were made when appropriate. Effect sizes were calculated using Cohen d.[22] Time-to-exhaustion data from the 3 NC trials were used to calculate the reliability of the test to exhaustion. Individual coefficients of variation were calculated for each participant between pairs of trials (ie, between FAM1 and FAM2 and between FAM2 and the 3rd NC trial) from which mean coefficients of variation for FAM1 and FAM 2 and for FAM2 and the 3rd NC trial pairings were calculated. The α level was set a priori at .05. We used SPSS (version 15; SPSS Inc, Chicago, IL) to analyze the data.

RESULTS

Time-to-Volitional Exhaustion Variability

The coefficients of variation of the time to volitional exhaustion between trial pairings were 8.7% between FAM1 and FAM2 and 8.0% between FAM2 and the 3rd NC trial (Figure 2). We found no difference between the coefficients of variation for the 2 trial pairings ($t_7 = 0.308$, $P = .77$).

Time to Volitional Exhaustion

Participants ran longer in the CC trials (43.15 ± 12.82 minutes) than in the NC trials (38.20 ± 11.70 minutes; $t_7 = 9.923$, $P < .001$, d = 0.44; Figure 2). The time to volitional exhaustion improved for all participants, with the observed individual percentage improvement ranging from 11.1% to 24.4% (Figure 3). The mean percentage improvement observed in the CC trials compared with the NC trials was 13.5% ± 3.8% (Figure 3).

Neck Skin Temperature

The Mauchly test indicated that the assumption of sphericity had been violated for neck skin temperature data for the main effects of time ($\chi^2_{14} = 36.969$, $P = .002$) and of interaction ($\chi^2_{14} = 25.802$, $P = .04$), so the degrees of freedom for this data set were corrected using Greenhouse-Geisser estimates ($\varepsilon = 0.477$ and 0.484, respectively). We found a main effect for trial. The application of the neck CC resulted in lower mean neck skin temperatures in the CC trials than in the NC trials ($F_{1,7} = 137.824$, $P < .001$, d = 6.28; Figure 4). We found a trial × time interaction ($F_{2.422,16.952} = 13.890$, $P < .001$, d = 1.99). The mean difference in neck skin temperature was greatest after 5 minutes (−17.91°C ± 3.95°C) and lowest at exercise termination (−8.11°C ± 4.59°C).

Heart Rate and Rectal Temperature

The assumption of sphericity was violated for HR data for the main effects of time ($\chi^2_{14} = 42.166$, $P < .001$) and

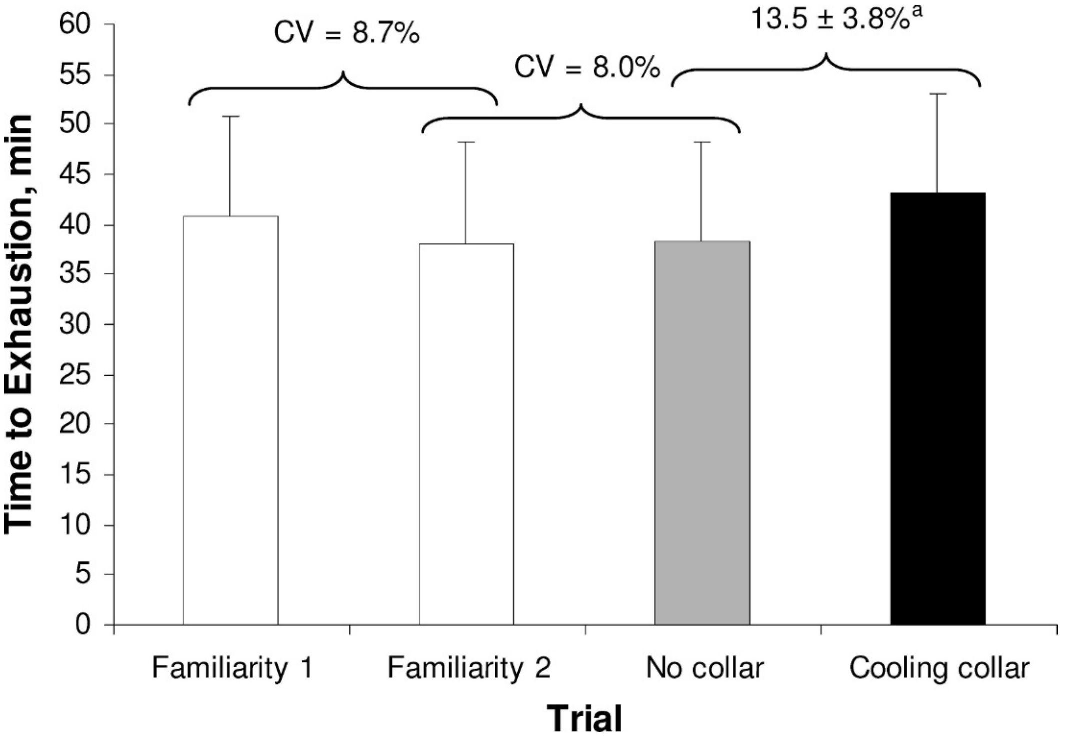

Figure 2. Time to volitional exhaustion for the reliability (familiarization 1, familiarization 2, no collar) and experimental (no collar, cooling collar) trials, mean ± SD. Abbreviation: CV, coefficient of variation. [a] Indicates $P < .001$ between trial pairings.

of interaction ($\chi^2_{14} = 38.947$, $P = .001$), so the degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.365$ and 0.288, respectively). Similarly, the Mauchly test indicated that the assumption had been violated for rectal-temperature data for the main effect of time ($\chi^2_{14} = 49.022$, $P < .001$) and for interaction ($\chi^2_{14} = 49.022$, $P < .001$), so the degrees of freedom for this data set also were corrected using Greenhouse-Geisser estimates ($\varepsilon = 0.249$ and 0.341, respectively). We found a main effect for trial. Wearing the CC resulted in elevated rectal temperatures ($F_{1,7} = 20.892$, $P = .003$, d = 2.44) and HRs ($F_{1,7} = 8.390$, $P = .02$, d = 1.55; Figure 5; Table). Participants commenced exercise at higher rectal temperatures in the CC trials (37.37°C ± 0.6°C) than in the NC

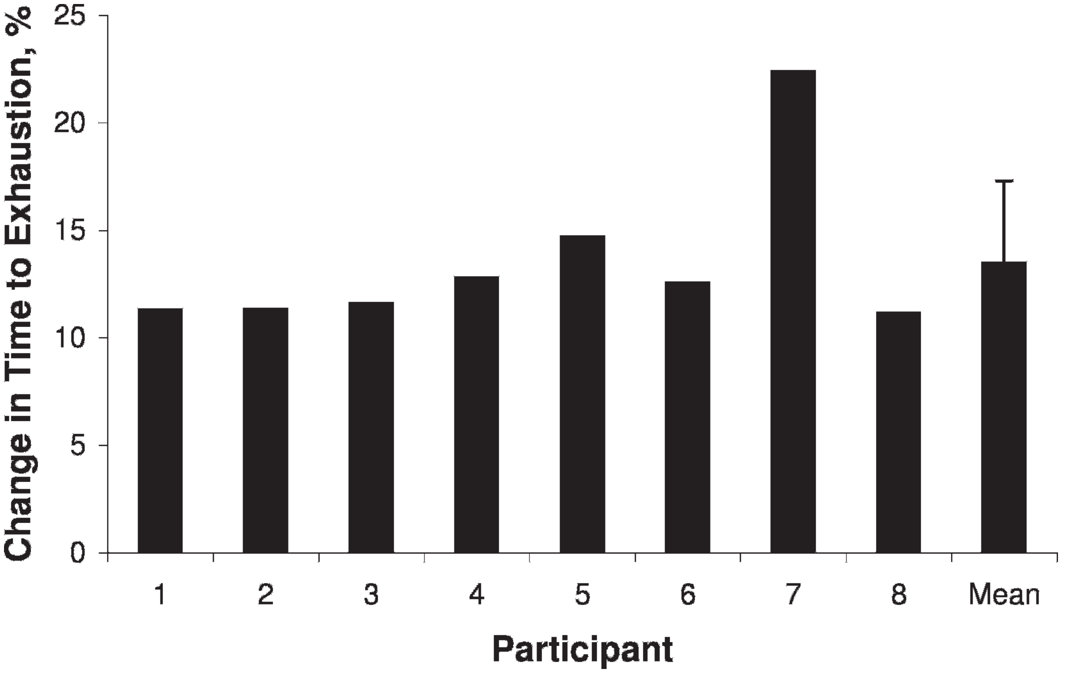

Figure 3. Percentage change in the time to volitional exhaustion with the cooling collar, individual and mean ± SD. A positive percentage represents an increase in the time taken to reach exhaustion.

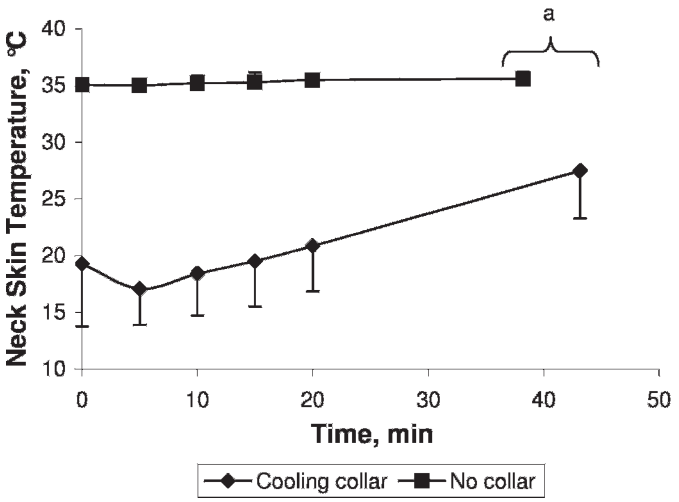

Figure 4. Neck skin temperatures observed in the cooling-collar and no-collar trials, mean ± SD. [a] Indicates $P < .001$ between trials. We found main effects of trial ($P < .001$) and time ($P < .001$) and an interaction ($P < .001$).

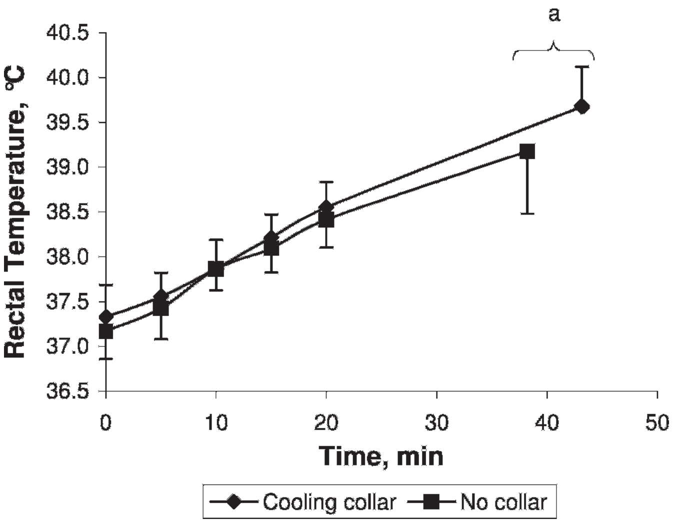

Figure 5. Rectal temperatures observed in the cooling-collar and no-collar trials, mean ± SD. [a] Indicates $P < .05$ between trials. We found main effects of trial ($P = .003$) and time ($P < .001$) and an interaction ($P = .02$).

trials (37.17°C ± 0.31°C; $t_7 = -2.491$, $P = .04$, d = 0.64). They also voluntarily terminated exercise at higher rectal temperatures in the CC trials (39.61°C ± 0.45°C) than in the NC trials (39.18°C ± 0.7°C; $t_7 = -3.217$, $P = .02$, d = 0.78) and at higher HRs in the CC trials (181 ± 6 beats/min) than in the NC trials (178 ± 9 beats/min; $t_7 = -2.664$, $P = .03$, d = 0.42).

Perceptual Measurements

The data for TS, TS$_{\text{neck}}$, rating of perceived exertion, and feeling scale are shown in the Table. We found a main effect for trial. The application of a CC reduced the perceived TS ($F_{1,7} = 14.258$, $P = .007$, d = 2.02) and TS$_{\text{neck}}$ ($F_{1,7} = 31.521$, $P = .001$, d = 3.0), meaning that participants felt cooler, but it had no effect on rating of perceived exertion ($F_{1,7} = 0.172$, $P = .69$) or feeling scale ($F_{1,7} < 0.001$, $P > .99$). We found no difference in the whole-body TS ($t_7 = 1.655$, $P = .14$) or rating of perceived exertion ($t_7 < 0.001$, $P > .99$) at the termination of exercise between trials. Thermal sensation of the neck was lower in the CC trials at the end of the trials ($t_7 = 4.103$, $P = .006$, d = 2.19).

Body Fluid Balance

We found no difference in the amount of chilled water voluntarily consumed in CC (427 ± 253 mL) and NC (452 ± 220 mL) trials ($t_7 = -0.709$, $P = .50$). We also found no difference in the total sweat lost in the CC (1.55 ± 0.53 L) and NC (1.51 ± 0.83 L) trials ($t_7 = -0.237$, $P = .82$), resulting in participants losing approximately 1.5% of their body mass during the CC (1.46% ± 0.74%) and NC (1.46% ± 1.29%) trials ($t_7 < 0.001$, $P > .99$).

DISCUSSION

Time to volitional exhaustion was improved when wearing the CC. Participants voluntarily terminated exercise at identical perceptions of exertion and thermal stress despite experiencing higher rectal temperatures and HRs at trial termination in the CC than in the NC trials. Therefore, the main findings from our study support the hypothesis that cooling the neck allows individuals to tolerate higher levels of thermal strain, which can enable them to exercise for longer in hot environments.

Exercise performance is impaired in hot compared with moderate environmental conditions,[1] and this impairment is attributed to a centrally regulated decrease in the pace selected during such self-paced exercise performance tests.[15,16] The mechanisms governing this decrease are unknown, but researchers have proposed that feedback from a variety of peripherally and centrally located receptors (eg, thermoreceptors, chemoreceptors, baroreceptors) provides information regarding the state of the body and results in the selection of a pacing strategy that enables the task to be completed within homeostatic limits.[15,16,23,24] This central governor theory was developed in opposition to the critical core temperature hypothesis, which proposes that exercise in the heat is limited because individuals can experience dangerously high core temperatures[4,5]; however, the models have very similar themes and, therefore, are not as contrasting as previously suggested. The central governor theory can only be applied to self-paced performance tests, whereas the critical core temperature theory can only be applied to fixed-intensity tests; this fundamental methodologic difference explains much of the conflict. Performance can be enhanced by approximately 6% in a hot environment with the application of a CC without any alterations in the physiologic response to the exercise bout.[2] It seemed prudent to suggest that the application of the CC might have provided a false signal regarding the body's thermal strain that allowed a faster pace to be adopted; however, the concept of the false signal was difficult to fully elucidate using a fixed- or known-endpoint performance test model.

The time to volitional exhaustion also is impaired in a hot environment,[3] and, when the intensity is fixed in such exercise tests, the point of voluntary exercise termination regularly occurs at core temperatures of approximately 40°C in laboratory investigations, regardless of the initial rectal temperature[4] or acclimation status.[5] Core tempera-

Table. Heart Rate and Perceptual Variables During the Treadmill Test to Volitional Exhaustion, Mean ± SD

Variable	Time 0 min	5 min	10 min	15 min	20 min	Fatigue
Heart rate, beats/min						
Cooling collar	91 ± 24	155 ± 13	162 ± 13	167 ± 13	169 ± 13	181 ± 6[a]
No collar	82 ± 15	153 ± 17	158 ± 16	162 ± 14	167 ± 12	178 ± 9
Rating of perceived exertion[b]						
Cooling collar	NA[c]	11.9 ± 1.8	12.6 ± 2.4	13.5 ± 2.6	14.6 ± 2.9	18.8 ± 1.0
No collar	NA[c]	11.4 ± 3.0	12.8 ± 2.4	13.5 ± 2.4	14.6 ± 2.7	18.8 ± 1.0
Thermal sensation[d]						
Cooling collar	4.3 ± 0.5	4.6 ± 0.7	5.0 ± 0.9	5.4 ± 0.9	5.7 ± 1.1	7.3 ± 0.6
No collar	4.2 ± 0.5	4.9 ± 0.6	5.5 ± 1.0	5.9 ± 1.0	6.1 ± 0.9	7.7 ± 0.4
Thermal sensation of the neck[d]						
Cooling collar	1.6 ± 1.2	2.9 ± 0.9	3.3 ± 0.7	3.6 ± 0.8	3.6 ± 0.9	5.3 ± 1.3[e]
No collar	4.2 ± 0.6	4.9 ± 0.7	5.6 ± 1.0	5.9 ± 1.1	6.1 ± 0.9	7.7 ± 0.4
Feeling scale						
Cooling collar	2.6 ± 2.1	3.0 ± 1.2	2.9 ± 1.2	2.6 ± 1.3	1.8 ± 2.2	−2.6 ± 1.2
No collar	3.5 ± 1.3	3.1 ± 1.7	2.6 ± 1.8	2.1 ± 2.2	1.3 ± 2.5	−2.4 ± 1.6

[a] Indicates difference between trials ($P < .05$).
[b] Rating scale range, 6 to 20.
[c] NA, not applicable.
[d] Rating scale range, 0 to 8.
[e] Indicates difference between trials ($P < .01$).

tures in excess of 40°C have been reported after marathon races. This demonstrates that high internal temperatures can be tolerated and that the mechanisms limiting exercise can be overridden when sufficient incentive and a high level of motivation exist.[7] Our data showed that cooling the neck region extended the time to reach volitional exhaustion by approximately 13.5%. Exercise was terminated at a higher rectal temperature when the neck region was cooled via the application of a neck CC. Participants voluntarily terminated exercise at a rectal temperature of 39.18°C ± 0.7°C in the NC trials but did not cease exercising until reaching an average temperature of approximately 0.4°C higher (39.61°C ± 0.45°C) in the CC trials ($t_7 = -3.217$, $P = .02$, d = 0.78). The HR at the termination of exercise was also higher in the CC trials; however, the subjective perceptual measurements revealed that, at the point of voluntary exercise termination, no difference existed in the level of thermal comfort or rating of perceived exertion. These data showed that participants reached voluntary exhaustion at similar perceived levels of thermal and physical stress and discomfort despite being under less thermal and cardiovascular strain in the NC trials. Similar findings were presented in 2 recent pharmacologic investigations in which cerebral concentrations of dopamine and noradrenaline were manipulated.[25,26] Roelands et al[25] and Watson et al[26] reported that higher levels of thermal and cardiovascular strain could be tolerated when cerebral dopamine concentrations were elevated and that the perceptual response to the level of strain was dampened. The excitability of cerebral dopaminergic neurons is temperature dependent,[27] so cerebral dopamine concentrations might be elevated by the application of the CC; however, this has not been investigated.

Authors[9] of precooling studies often have reported improvements in subsequent exercise performance and time to volitional exhaustion and have attributed the improvements to a reduction in the rectal temperature at any given comparative point; however, improvements in a subsequent exercise bout have been observed without reductions in core temperature.[10] This suggests that the benefit observed might not be dependent wholly on a reduction in core temperature and that the benefit might be due to an alternative cooling-induced alteration in the actual or perceived state of the body. Our data demonstrated that, during fixed-intensity exercise, cooling the neck region can dampen the perceived levels of TS and rating of perceived exertion, because participants' subjective ratings were the same despite higher core temperatures at commencement of and throughout exercise and higher HRs during the exercise bouts. Investigators[2,28] have reported that cooling the neck region has no effect on the core temperature or HR response to exercise, but, in both of these studies, the participants were exercising in cooler temperatures (30°C versus 32°C) and at a lower intensity (60% versus 70% VO_{2max}) for most of the test. The effectiveness of cooling the head region in enhancing exercise capacity has been shown to depend on the level of thermal strain experienced,[29] and this might explain the differences observed. The elevation in core temperature despite the fixed work intensity suggests that cooling the neck region might alter the thermoregulatory drive and suppress the heat-loss mechanisms. However, the higher core temperatures observed during the exercise might have been due to unsystematic variation, as demonstrated by the higher mean starting core temperature. A suppressed heat-loss mechanism and a reduced perceived level of thermal strain both have potentially serious implications for the health and well-being of the participant. Subjective ratings help to regulate exercise intensity[30]; therefore, any intervention that manipulates or dampens this feedback might be dangerous if it results in higher core temperatures.

Researchers[31] have shown that brain, rather than core, temperature is the main determinant of exercise capacity, so another possible reason for the ergogenic effect of cooling the neck is a direct cooling of the arterial blood and a subsequent reduction in brain temperature. The preoptic and anterior regions of the hypothalamus, which make up the thermoregulatory center, are supplied primarily by the anterior cerebral and anterior communicating arteries.[32] These arteries are supplied by the internal carotid artery; this relationship demonstrates the direct route that the arterial blood takes from the carotid arteries to the thermoregulatory center and explains why investigators have proposed that neck cooling might lower brain temperature. Using mathematical modeling, researchers have computed that a reduction in brain-surface temperature is possible to a depth of approximately 3 to 4 mm based upon typical cerebral blood flow and that reduced cerebral blood flow, as is observed during hyperthermic exercise,[33] would increase the depth of cooling achieved.[34] Although these researchers have computed that external cooling theoretically can reduce brain temperature, no one has established whether the cooling induced is practically significant or can occur in a human model. We did not measure cerebral blood flow or arterial temperature, so we acknowledge that a reduction in neck skin temperature does not necessarily mean a similar reduction in arterial blood temperature.

An inherent problem with cooling studies is the inability to blind the participants to the intervention and the resultant possibility of a placebo effect. In a recent review on the placebo effect in sports performance, Beedie and Foad[35] stated that both positive and negative placebo effects ranging from −1.9% to 50.7% have been reported on sport performance; however, most investigators have reported a positive effect of 1% to 5%. Although the magnitude of any cooling-induced placebo effect has not been established, the improvements in the time taken to reach volitional exhaustion observed in our study are far greater than the 1% to 5% reported. The CC also had no effect on the subjective perceptions of exertion or pleasure/displeasure. If the improvement observed was due to a placebo effect, it would have been mirrored by improvements in perceived levels of pleasure, but this was not the case, suggesting a real, rather than placebo, effect.

Effective, practical strategies to offset the reductions observed in exercise performance and capacity in hot compared with moderate environments have long been sought by athletes and members of their support teams. The neck region is an area of high allesthesial thermosensitivity and also is an area that can be cooled effectively with minimal disruption to sporting actions or attire. Our study showed that cooling the neck region via a practical CC can increase the time taken to reach volitional exhaustion in hot environments by 13.5% by dampening the perceived level of thermal strain. Cooling the surface of the neck allowed the participants to tolerate higher rectal temperatures and HRs; however, they terminated exercise at identical levels of TS and rating of perceived exertion. Because of the dampened perception of thermal state, effective monitoring and briefing procedures are required to ensure the individual's safety during exercise performed in a hot environment with a cooling device applied. These procedures should be adopted and followed by both the potential user (eg, athlete) and those with a duty of care to the adopter (eg, coach, athletic trainer, health professional).

CONCLUSIONS

Cooling the neck region allowed participants to tolerate higher rectal temperatures and HRs before they voluntarily terminated exercise at identical levels of perceived thermal comfort and ratings of perceived exertion in a hot environment. In our study, this dampening of the perceived level of thermal strain enabled participants to increase the time taken to reach volitional exhaustion. These data suggested that cooling this region masks the true state of the body, delaying the point at which the voluntary termination of exercise occurs.

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