Neck Cooling and Running Performance in the Heat: Single versus Repeated Application

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ABSTRACT

TYLER, C. J., and C. SUNDERLAND. Neck Cooling and Running Performance in the Heat: Single versus Repeated Application. *Med. Sci. Sports Exerc.*, Vol. 43, No. 12, pp. 2388–2395, 2011. **Purpose**: This study aimed to evaluate the effect of sustained neck cooling during time trial running in a hot environment. **Methods**: Seven nonacclimated, familiarized males completed three experimental 90-min preloaded time trials in the heat (30.4°C ± 0.1°C and 53% ± 2% relative humidity). During one of the trials, the, participants wore a cooling collar from the start (CC); in another, they wore a collar from the start which was replaced at 30-min intervals ($CC_{replaced}$); and in the last trial, they wore no collar (NC). Participants ran for 75 min at 60% $\dot{V}O_{2max}$ and then performed a 15-min time trial blinded from the distance ran. Distance ran, rectal temperature, neck skin temperature, HR, fluid loss and consumption, peripheral lactate, glucose, dopamine, serotonin and cortisol, RPE, thermal sensation, and feeling scales were recorded. Significance was set *a priori* at the $P < 0.05$ level. **Results**: Participants ran further in CC (2779 ± 299 m) compared with NC (2597 ± 291 m, $P = 0.007$; $d = 0.67$) and in $CC_{replaced}$ (2776 ± 331 m) compared with NC ($P = 0.008$; $d = 0.62$). There was no difference in the distance covered in CC compared with that in $CC_{replaced}$ ($P = 0.998$). The collar lowered neck temperature ($P < 0.001$) and the thermal sensation of the neck region ($P < 0.001$) but had no effect on any of the other physiological, endocrinological, or perceptual variables. **Conclusions**: Cooling the surface of the neck improves time trial performance in a hot environment without altering physiological or neuroendocrinological responses. Maintenance of a lower neck temperature via the replacement of a CC has no additional benefit to an acute cooling intervention.

Key Words: HYPERTHERMIA, THERMOREGULATION, TREADMILL, EXHAUSTION, FATIGUE, PACING

It is well documented that exercise performance is impaired when ambient temperatures are high (32,33) and previous research has demonstrated that, after a 75-min submaximal preload bout of exercise, a 15-min time trial performance is impaired in hot (30°C) compared with moderate (14°C) conditions by ~10% (33). The impairment observed in exercise performed in hot conditions is often attributed to the development of hyperthermia because, in laboratory-based investigations, volitional exhaustion is typically associated with core temperatures of ~40°C regardless of the initial temperature, acclimation status, or hydration levels of the study's participants (12,22). Because elevated body temperature has been heavily implicated in the reduced ability to exercise in the heat, the effectiveness of several different cooling strategies has been investigated (18,26).

Precooling has consistently been shown to enhance subsequent prolonged exercise performance in the heat (1,2,18,26); however, traditionally, this has involved water immersion, which has limited "real-world" utility because of the equipment required and the disruption to normal precompetition athletic practices. As a result, more practical alternatives have been investigated, such as the wearing of a cooling jacket or vest (1,10,11,38) or a cooling collar (CC) (5,13,34,35). Most of these studies have reported that such devices were unable to provide a sufficiently sustained cooling effect to elicit physiological alterations, and this is particularly the case with the neck cooling devices that have been investigated so far (5,13,34,35).

Cooling the neck specifically seems worthy of investigation because the head, neck, and face are regions of high alliesthesial thermosensitivity (9), and it has previously been shown that cooling the neck may be more effective in the alleviation of heat strain than cooling the same surface area of the trunk (31). Cooling the head via a water-perfused garment has been shown to improve time trial performance in a hot environment (25), while cooling the neck region via a practical CC has been shown to significantly enhance 15-min preloaded treadmill time trial performance (35) as well as treadmill running capacity (34) in hot environmental conditions (30°C–32°C and ~50% relative humidity (RH)). It is worth noting that wearing the collar uncooled impaired performance compared with the CC trials but had no effect compared with no-cooling, control trials (35). Despite alterations in running performance and capacity, cooling the neck via the practical CC and wearing the collar uncooled had no

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effect on any of the physiological or neuroendocrinological variables measured (34,35); a result that replicated those reported by previous neck cooling studies (5,13).

Sustained cooling of the head during a bout of rest, followed by exercise, has been shown to improve time trial performance in the heat compared with when the cooling stimulus was removed before exercise (25). No data were provided regarding the effect of cooling the neck exclusively at rest compared with no cooling; however, data from this and another study (35) suggest that sustained cooling of the head or neck might offer a cumulative benefit to exercise undertaken in a hot environment. The effectiveness of any cooling intervention to alter physiological or neuroendocrinological variables seems to be dependent on the difference between the magnitude of the cooling and the thermal strain experienced (4,23), and the greatest benefits are often reported when the thermal strain is at its most severe (23). To date, no research has investigated the effect of sustained neck cooling on prolonged exercise performance.

In a previous investigation (35), time trial performance has been shown to be improved by cooling the neck region in a 90-min preloaded time trial, although the cooling effect was no longer in existence at the onset of the performance test period. If the benefit of a cooling intervention is largely dependent on the difference between the level of cooling provided and the level of thermal strain experienced (23,25,35), it would seem prudent to suggest that providing a sustained bout of cooling during the 90-min preloaded time trial would have a cumulatively beneficial effect on time trial performance. On the basis of previous neck cooling literature (34,35), it was hypothesized that the additional performance improvement would occur as a result of a greater improvement in the perceived level of strain experienced and not as a result of the additional cooling affecting the physiological or hormonal response to the exercise. However, the effectiveness of cooling interventions has been shown to be dependent on the difference between the magnitude of the cooling and the thermal strain experienced (4,23) and so it is possible that sustained cooling may affect theses variables, and therefore, they were measured in the present study. The aims of the current study were to test this hypothesis and to investigate the effect of maintaining the neck at a reduced temperature, via the replacement of the CC, throughout the 90-min protocol.

METHODS

Participants. Seven healthy, trained, nonacclimated males volunteered for the study. Mean ± SD age, body mass, height, and relative maximal oxygen uptake ($\dot{V}O_{2max}$) of the participants were 25 ± 2 yr, 75.3 ± 8.4 kg, 1.79 ± 0.05 m, and 55.3 ± 3.6 $mL \cdot kg^{-1} \cdot min^{-1}$. It was calculated that a sample size of seven would provide sufficient statistical power (0.8; $\beta = 0.2$) based on an effect size of $d = 0.45$, an α level of 0.05, and a correlation between repeated measures of >0.9 (35). *Post hoc* power analysis revealed an achieved power of 0.9. The participants were fully informed of any risks and discomforts associated with the study before giving their oral and written informed consent to participate and completing a health screen. The health screening procedure was repeated before each laboratory visit to assess the health status of the individual. The study was approved by Nottingham Trent University's Ethical Advisory Committee.

Experimental procedures. Before the main trials, participants completed an incremental motorized treadmill test to determine $\dot{V}O_{2max}$ (16). After a full familiarization trial, participants visited the laboratory on three occasions for the main experimental trials. The trials were conducted in a randomized and counterbalanced order. All trials were conducted using an electric, motorized, treadmill (h/p/cosmos Quaser Sport; h/p/cosmos sports and medical GmbH Nussdorf-Traunstein, Germany). The experimental trials were conducted at the same time of the day on each occasion ± 30 min and were separated by 7 d. Participants were not naturally acclimatized to a hot environment, and all trials occurred during the cooler months of the year (mean outdoor temperature on the mornings of the main trials = 8.1 ± 3.6°C).

During the familiarization and experimental trials, participants completed a 90-min preloaded time trial (TT_{pre}) in hot conditions (30.4°C ± 0.1°C and 53% ± 2% RH)in a walk-in environmental chamber (Design Environmental WIR52-20HS; Design Environmental Ltd., Gwent, UK). The TT_{pre} consisted of 75 min of treadmill running at ~60% $\dot{V}O_{2max}$ (9.0 ± 1.0 $km \cdot h^{-1}$) followed by a self-paced 15-min time trial during which participants were manually able to increase and decrease their speed. Participants were instructed to cover as much distance as they could during the time trial; the time remaining during the performance test was displayed via a countdown timer. The distances covered were not revealed until the completion of all four trials (one familiarization trial and three experimental trials). Previous research has shown that the coefficient of variation of this protocol conducted in hot conditions and with similar participants after a familiarization trial is 2.7% (33).

During the three experimental trials, participants completed the TT_{pre} while wearing either a cold collar applied at the start and worn for the duration of the 90-min trial (CC), a cold collar worn from the start and replaced twice during the TT_{pre} at 30 and 60 min ($CC_{replaced}$), or no collar (NC). The collar used was a modified commercially available collar (Black Ice LLC, Lakeland, TN) as used in previous studies (34,35). The cooling section of the modified Black Ice CC was made from a thin plastic casing consisting of five compartments that were drained of the Black Ice cooling reagent and filled with ~120 g of gel refrigerant (BDH Laboratory Supplies, Poole, Dorset, UK). An in-house pilot work established that the gel refrigerant provided the greatest magnitude of cooling without resulting in tissue damage (unpublished observations). 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 (*L*) × 60 mm (*W*) × 15 mm (*D*), and it weighed 155 g at room temperature. Before the neck CC trials, the collar was frozen for 24–28 h in a freezer at −80°C and was then left for 10 min in ambient conditions before being cleared of any surface frost before application.

Participants completed a food record for the day before the initial experimental trial. They adopted the same diet and abstained from alcohol and caffeine as well as strenuous exercise for 24 h, before each main trial. Participants arrived at the laboratory ~30 min before the commencement of the trial in a fasted (≥10 h postprandial) state and having ingested 500 mL of water ~1.5 h previously. On arrival, nude body mass was recorded (Seca, Birmingham, UK). A rectal probe (Grant Instruments (Cambridge) Ltd., UK) was self-inserted ~10 cm past the anal sphincter, an HR monitor (Polar Electro Oy, Kempele, Finland) was attached, and an indwelling cannula (Venflon; Becton Dickinson UK Ltd., Oxford, UK) was inserted into a vein of the antecubital fossa before the participant entered the environmental chamber. The indwelling cannula was kept patent by an injection of saline (~5 mL) after each sample. Participants rested in the environmental chamber in an upright position for 10 min, after which resting values for HR, rectal temperature (T_{rectal}), mean neck skin temperature (T_{neck}), feeling scale (14) (FS), whole-body thermal sensation (39) (TS), and thermal sensation of the neck (TS_{neck}) were obtained. The collar was then placed around the neck in the CC and $\text{CC}_{\text{replaced}}$ trials. Mean neck skin temperature was calculated as the mean temperature of four skin thermistors (Grant Instruments (Cambridge) Ltd.) spaced equally across the posterior aspect of the neck. One thermistor was placed superior to the anterior aspect of both the left and right carotid arteries, located via palpation, whereas the remaining two thermistors were placed either side of the spinal midline at approximately the third or fourth cervical vertebrae. All thermistors were attached via a transparent dressing (Tagaderm; 3M Health Care, St. Paul, MN) and waterproof tape (Transpore; 3M Health Care). A nine-point scale, ranging from 0 (unbearably cold) to 8 (unbearably hot) with 4 as comfortable (neutral), was used to measure TS and TS_{neck} (39). The FS assessed levels of pleasure and displeasure using an 11-point scale ranging from −5 (very bad) to +5 (very good) with 0 (neutral) as the midpoint (14). Chilled water (7.5°C ± 2.9°C) was allowed *ad libitum* during all of the trials.

During the 90-min TT_{pre}, HR, T_{rectal}, T_{neck}, RPE (3), FS, TS, and TS_{neck} were recorded at 5-min intervals. The distances ran during the 75-min preload phase and the subsequent 15-min time trial were noted. The self-selected pace was recorded at minute intervals during the time trial phase of each experimental trial. After the completion of each trial, participants towel-dried and recorded a dry postexercise nude body mass from which sweat loss and the percentage change in body mass was calculated, taking into account voluntary fluid consumption during the protocol.

Collection and analysis of blood samples. Venous blood samples were taken at 0, 10, 40, 70, and 90 min at which times participants were stationary. All blood samples were taken within 2 min; therefore, participants were stationary for <6 min during the 90-min trial and were not disturbed during the time trial phase. Whole blood was initially analyzed for lactate and glucose (2300 STAT plus; Yellow Springs Instruments, Inc., Yellow Springs, OH), and then aliquots were dispensed into K_3-EDTA tubes (Sarstedt Ltd., Leicester, UK). The aliquots were then centrifuged at 4000*g* for 10 min at 4°C. After centrifuging, the supernatant was removed and then frozen at −80°C until the analyses were performed.

Changes in blood, plasma, and red cell volume were calculated from the mean hemoglobin concentration (B-hemoglobin photometer; Hemocue AB, Angelholm, Sweden; measured in triplicate), and the mean hematocrit (Micro Centrifugation; Hawksley, Sussex, UK; measured in triplicate) was measured using the methods of Dill and Costill (9a).

Plasma concentrations of cortisol, dopamine, and serotonin were determined via enzyme-linked immunosorbent assays: cortisol (DRG Instruments GmbH, Marburg, Germany) and dopamine and serotonin (IBL Hamburg, Hamburg, Germany). The intra-assay coefficients of variation for the cortisol, dopamine, and serotonin assays were 4.3%, 8.1%, and 5.7%, respectively.

Statistical analyses. Descriptive data are reported as mean ± SD. One-way repeated-measures ANOVA tests were conducted to evaluate differences between the distances ran, sweat loss, fluid consumption, and changes observed during the trial, whereas two-way (trial × time) tests were performed to evaluate differences between trials for thermoregulatory, cardiovascular, neuroendocrinological, and perceptual variables. After a significant *F* value, the Tukey HSD *post hoc* tests were conducted to identify pairwise differences. Violations of sphericity were adjusted for using the Greenhouse–Geisser adjustment when appropriate. The effect size (*d*) of all significant differences was calculated using trial pairings (7). Baseline variability was assessed via coefficient of variation. Significance was set *a priori* at the $P < 0.05$ level.

RESULTS

Time trial performance. During the time trial phase, participants covered 2597 ± 291, 2779 ± 299, and 2776 ± 331 m in the NC, CC, and $\text{CC}_{\text{replaced}}$ trials, respectively (Fig. 1). There was a significant main effect for trial ($F_{2,12} = 9.4$, $P = 0.003$). Significantly more distance was covered in CC compared with NC ($P = 0.007$, $d = 0.67$) and in $\text{CC}_{\text{replaced}}$ compared with NC ($P = 0.008$, $d = 0.62$). There was no significant difference in the distance covered in CC compared with $\text{CC}_{\text{replaced}}$ ($P = 0.998$). The self-selected pace was significantly faster toward the end of the time trial (main effect of time, $F_{14,84} = 34.3$, $P < 0.001$), but there was no

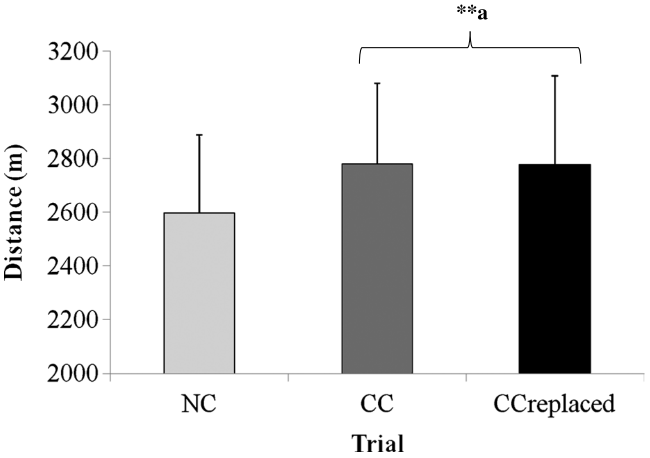

FIGURE 1—Mean ± SD distances covered during the 15-min time trials in the NC, CC, and CC$_{replaced}$ trials. **P < 0.01. [a]Compared to NC. Main effect of trial (P = 0.003).

significant difference between trials for the pacing strategy selected (main effect of trial, $F_{2,12}$ = 1.4, P = 0.283). Individual percentages of time trial performance differences compared with NC trials are presented in Figure 2. The mean percentage improvement in time trial performance compared with NC was 7.3% in CC and 6.9% in CC$_{replaced}$. No trial-order effect was observed for the distances ran (P = 0.926).

Neck temperature. Mean neck skin temperature is shown in Figure 3. There was a significant main effect for trial ($F_{2,12}$ = 145.6, P < 0.001), time ($F_{18,108}$ = 33.7, P < 0.001), and trial × time interaction ($F_{36,216}$ = 12.6, P < 0.001). T_{neck} was significantly colder during the 90-min TT$_{pre}$ in CC compared with NC (P < 0.001), CC$_{replaced}$ compared with NC (P < 0.001), and CC$_{replaced}$ compared with CC (P = 0.003). At the commencement of the time trial (t = 75 min), there was a significant main effect for trial ($F_{2,12}$ = 73.2, P < 0.001), and neck temperature was significantly lower in CC$_{replaced}$ compared with NC and CC trials (P < 0.001 for both); however, there was no significant difference between NC and CC (P = 0.210). Neck temperature remained significantly lower until the 55th min in CC (P < 0.05) and for the duration of CC$_{replaced}$ (P < 0.001) compared with NC.

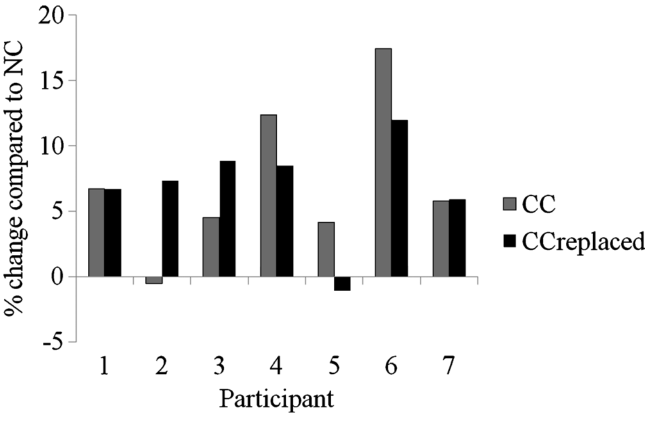

FIGURE 2—Individual performance changes (%) compared with the NC trial for the CC and CC$_{replaced}$ trials.

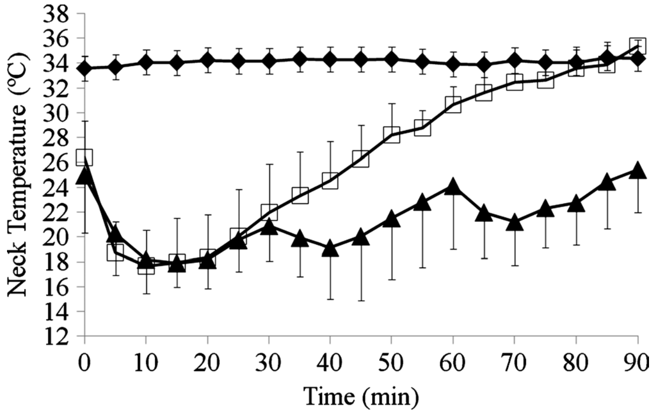

FIGURE 3—Mean ± SD neck temperature during the 90-min preloaded time trials. ♦, NC; □, CC; ▲, CC$_{replaced}$. Main effect of time (P < 0.001), trial (P < 0.001), and interaction (P < 0.001). Neck temperature remained significantly lower until the 55th min in CC (P < 0.05) and for the duration of CC$_{replaced}$ (P < 0.001) compared with NC.

HR and rectal temperature. HR and T_{rectal} increased significantly during the trial (main effect of time on HR, $F_{18,108}$ = 203.4, P < 0.001; main effect of time on T_{rectal}, $F_{18,108}$ = 206.4, P < 0.001); however, there were no significant differences between trials for T_{rectal} ($F_{2,12}$ = 1.3, P = 0.320) or HR ($F_{2,12}$ = 0.8, P = 0.454). There were no significant differences between trials in the changes observed between 0 and 90 min for T_{rectal} ($F_{2,12}$ = 0.3, P = 0.727) or HR ($F_{2,12}$ = 0.79, P = 0.478). Further analysis revealed that there were no significant differences between trials for T_{rectal} or HR at the commencement of the time trial phase (t = 75 min) ($F_{2,12}$ = 0.7, P = 0.496 and $F_{2,12}$ = 0.6, P = 0.583, respectively). T_{rectal} and HR data observed at 0, 75, and 90 min are shown in Table 1.

Perceptual measurements. All perceptual data (TS, TS$_{neck}$, RPE, FS) significantly changed over time (main effect of time on TS, $F_{18,108}$ = 32.4, P < 0.001; main effect of time on TS$_{neck}$, $F_{18,108}$ = 47.8, P < 0.001; main effect of time on RPE, $F_{17,102}$ = 50.0, P < 0.001; main effect of time on FS, $F_{18,108}$ = 10.3, P < 0.001). There were no significant main trial or interaction effects for RPE or FS ($F_{2,12}$ = 0.7, P = 0.540 and $F_{2,12}$ = 0.03, P = 0.971, respectively).There was no main trial effect ($F_{2,12}$ = 3.4, P = 0.1) for TS, but there was a significant interaction (trial × time, $F_{36,216}$ = 1.6, P = 0.002). TS$_{neck}$ was significantly different between trials (main effect of trial, $F_{2,12}$ = 22.8, P < 0.001) and was lower in CC$_{replaced}$ compared with NC (P = 0.003) and CC (P = 0.004) and in CC compared with NC (P = 0.006) (Fig. 4).

At the beginning of the time trial (75 min), there was no significant difference between trials for RPE ($F_{2,12}$ = 2.3, P = 0.143), but there was a difference between trials for TS ($F_{1.1,6.4}$= 7.7, P = 0.029). Participants reported feeling significantly cooler in CC$_{replaced}$ compared with CC (P = 0.001), but there were no differences between NC and CC (P = 0.599) or between NC and CC$_{replaced}$ (P = 0.334). There was a significant main effect for TS$_{neck}$ ($F_{2,12}$ = 18.5,

TABLE 1. Rectal temperature and HR at 0, 75, and 90 min and the change observed in both variables during the 90-min trial.

Time (min)	Trial	Rectal Temperature (°C)	HR (bpm)
0	NC	36.68 ± 0.25	68 ± 12
	CC	36.53 ± 0.67	76 ± 16
	$CC_{replaced}$	36.72 ± 0.28	77 ± 11
75	NC	38.50 ± 0.35*[a]	160 ± 14*[a]
	CC	38.50 ± 0.51*[a]	158 ± 8*[a]
	$CC_{replaced}$	38.58 ± 0.38*[a]	157 ± 9*[a]
90	NC	38.91 ± 0.29*[a,b]	185 ± 9*[a,b]
	CC	38.90 ± 0.53*[a,b]	186 ± 11*[a,b]
	$CC_{replaced}$	38.97 ± 0.36*[a,b]	185 ± 11*[a,b]
Δ90	NC	2.23 ± 0.24	116 ± 13
	CC	2.36 ± 0.60	110 ± 17
	$CC_{replaced}$	2.25 ± 0.32	108 ± 16

Values are means ± SD.

No significant differences existed between trials at any time point (T_{rectal}, $P = 0.391$; HR, $P = 0.355$). No significant differences were observed in the change in T_{rectal} (Δ90; $P = 0.727$) or HR ($P = 0.478$).

* $P < 0.01$.

[a] Significant difference compared with 0 min.

[b] Significant difference compared with 75 min.

$P < 0.001$). Pairwise comparisons revealed that participants reported a significantly lower TS_{neck} in $CC_{replaced}$ compared with CC ($P = 0.006$) and NC ($P = 0.013$), but there was no difference between CC and NC ($P = 0.127$).

Body fluid balance. There were no significant differences in the volume of water voluntarily consumed ($F_{2,12} = 2.2$, $P = 0.152$) or in the volume of sweat lost ($F_{2,12} = 2.0$, $P = 0.183$) between trials. Participants consumed 0.85 ± 0.50, 0.90 ± 0.50, and 0.68 ± 0.24 L of water and lost 2.01 ± 0.39, 2.18 ± 0.31, and 1.88 ± 0.19 L of sweat during the NC, CC, and $CC_{replaced}$ trials. There was a trend for participants to drink less and lose less body mass in $CC_{replaced}$ trials; however, because of the large individual differences, there were no significant differences observed. The mean plasma volume changes observed in the NC, CC, and $CC_{replaced}$ were −2.4% ± 8.27%, 0.4% ± 6.4%, and −5.8% ± 8.2% ($F_{2,12} = 0.6$, $P = 0.583$).

Blood data. Whole-blood lactate and glucose concentrations increased over time (main effect of time on lactate, $F_{1.9,11.3} = 105.4$, $P < 0.001$; main effect of time on glucose, $F_{1.8,11.1} = 4.9$, $P = 0.005$), but there were no significant main effect differences between trials for whole blood lactate ($F_{2,12} = 1.7$, $P = 0.216$) or glucose ($F_{2,12} = 0.1$, $P = 0.866$). There was no significant increase in cortisol levels over time ($F_{4,24} = 2.0$, $P = 0.139$) or significant differences between trials ($F_{2,12} = 1.5$, $P = 0.269$). Plasma concentrations of cortisol, serotonin, and dopamine are displayed alongside whole-blood lactate and glucose concentrations in Table 2. Concentrations of serotonin and dopamine increased over time (main effect of time on serotonin, $F_{4,24} = 5.7$, $P < 0.03$; main effect of time on dopamine, $F_{4,24} = 20.6$, $P < 0.001$); however, there was no difference between trials for either neurotransmitter (main effect of trial on serotonin, $F_{2,12} = 0.8$, $P = 0.462$; main effect of trial on dopamine, $F_{2,12} = 0.5$, $P = 0.790$). Baseline concentrations of neuroendocrinological showed some variability between trial days (cortisol = 20% ± 6%, serotonin = 33% ± 15%, dopamine = 18% ± 8%). There were no significant differences between trials for the magnitude of change during the 90 min for cortisol ($F_{2,12} = 3.4$, $P = 0.075$), serotonin ($F_{2,12} = 3.9$, $P = 0.055$), or dopamine ($F_{2,12} = 0.4$, $P = 0.716$) (Table 2).

DISCUSSION

The main finding of the current study is that replacing the cold collar at regular intervals improves time trial performance by 6.9% in the heat but offers no cumulative or additional benefit to that provided without replacing the cold collar. In the CC trial, performance was improved by ~7.3% compared with the NC control trial, which confirms previous research that demonstrated that cooling the neck region via a practical CC improved the 15-min time trial performance in the heat (35).

There was no cumulative benefit of the sustained cooling in the present study, which is in contrast to previous literature that has suggested that the beneficial effects of a cooling intervention are dependent on a sufficient level of cooling provided and/or thermal strain experienced (23,25). For example, Nunneley et al. (23) reported that cooling the head had no effect on core temperature in trials conducted at 20°C and 30°C; however, it did reduce core temperature in the 40°C trials when the thermal strain was greatest. In an exercise setting, Palmer et al. (25) reported that sustained cooling of the head region during a bout of rest and subsequent exercise improved 15-min treadmill performance in a hot environment (33°C; 55% RH) by ~2.5% compared with cooling at rest alone. No data comparing cooling at rest to no cooling were provided, but the data provided regarding cooling at rest versus cooling at rest and during exercise offered further tentative support for the notion of a cumulative benefit of sustained cooling. Such a benefit was not observed in the current study.

Unlike the present study, Palmer et al. (25) reported a reduction in rectal temperature with the sustained head cooling. Because of the inverse relationship observed

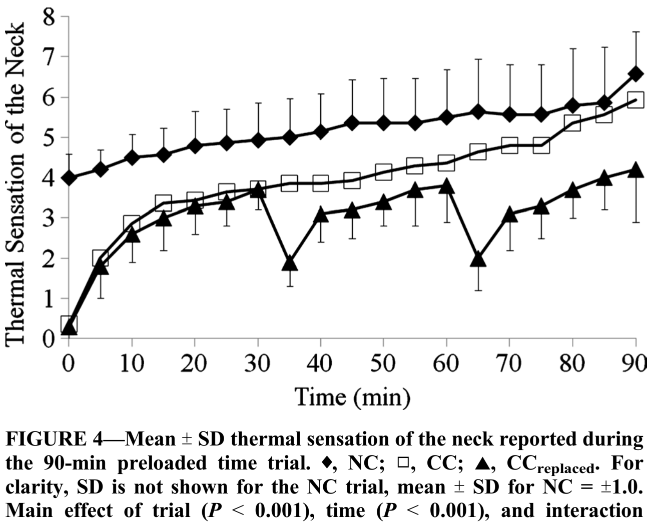

FIGURE 4—Mean ± SD thermal sensation of the neck reported during the 90-min preloaded time trial. ◆, NC; □, CC; ▲, $CC_{replaced}$. For clarity, SD is not shown for the NC trial, mean ± SD for NC = ±1.0. Main effect of trial ($P < 0.001$), time ($P < 0.001$), and interaction ($P < 0.001$).

TABLE 2. Blood cortisol, serotonin, dopamine, lactate, and glucose concentrations at select time points and observed changes during the 90-min preloaded time trial.

	0 min	10 min	40 min	70 min	90 min	Δ90 min
Cortisol (nmol·L^{-1})						
NC	370.5 ± 85.1	338.7 ± 81.9	308.2 ± 120.9	332.4 ± 170.3	387.3 ± 195.4	16.8 ± 201.8
CC	347.8 ± 83.6	360.5 ± 79.1	332.2 ± 105.8	394.9 ± 114.4	496.3 ± 144.7	148.5 ± 192.5
CC$_{\text{replaced}}$	373.7 ± 95.7	409.1 ± 70.8	371.0 ± 82.6	352.5 ± 131.4	446.7 ± 175.6	73.0 ± 132.5
Serotonin (nmol·L^{-1})						
NC	80.7 ± 48.5	80.7 ± 73.8	68.2 ± 42.4	73.1 ± 52.9	173.9 ± 93.8*	93.2 ± 122.7
CC	48.0 ± 32.3	103.6 ± 118.6	134.4 ± 172.2	115.2 ± 115.3	210.2 ± 86.5*	162.8 ± 80.1
CC$_{\text{replaced}}$	81.8 ± 71.2	76.5 ± 57.2	57.2 ± 24.9	57.5 ± 34.3	89.2 ± 69.8*	7.39 ± 43.86
Dopamine (nmol·L^{-1})						
NC	0.69 ± 0.29	0.78 ± 0.50	0.85 ± 0.26	1.02 ± 0.26	1.80 ± 0.52**	1.10 ± 0.73
CC	0.67 ± 0.14	0.83 ± 0.23	0.93 ± 0.22	0.93 ± 0.14	1.62 ± 0.31**	0.95 ± 0.33
CC$_{\text{replaced}}$	0.56 ± 0.19	0.58 ± 0.15	0.76 ± 0.12	1.02 ± 0.26	1.51 ± 0.26**	0.95 ± 0.41
Lactate (mmol·L^{-1})						
NC	0.94 + 0.26	1.54 + 0.63	1.56 + 0.75	1.70 + 0.79	6.19 + 1.43**	5.25 ± 1.37
CC	1.01 ± 0.32	1.47 ± 0.43	1.71 ± 1.18	1.45 ± 0.66	6.77 ± 1.31**	5.76 ± 1.44
CC$_{\text{replaced}}$	0.93 ± 0.43	1.35 ± 0.38	1.37 ± 0.48	1.36 ± 0.47	5.88 ± 1.43**	4.95 ± 1.70
Glucose (mmol·L^{-1})						
NC	4.17 ± 0.29	3.88 ± 0.30	4.13 ± 0.29	3.83 ± 1.12	4.71 ± 1.07*	0.54 ± 0.97
CC	3.97 ± 0.42	3.82 ± 0.23	3.99 ± 0.44	4.01 ± 0.30	4.96 ± 0.96*	0.99 ± 0.95
CC$_{\text{replaced}}$	4.00 ± 0.39	3.67 ± 0.40	4.09 ± 0.31	4.11 ± 0.23	4.58 ± 0.89*	0.57 ± 0.94

* $P < 0.05$, significant difference from other time points.

** $P < 0.001$, significant difference from other time points.

Δ90 min, change observed during the trial (90 min−0 min).

between the ability to exercise and the levels of hyperthermia (12), the improvement in performance observed could be, in part, due to this reduction. In previous experimental studies investigating the practical CC used in this study (34,35), the collar was shown to have no effect on the physiological or hormonal responses to the exercise bout. The current study replicated these findings, and it was established that replacing the collar at 30-min intervals also had no effect on the rectal temperature or HR response to the 90-min preloaded time trial and that the hormonal response also remained unaffected. Reductions in core temperature caused by cooling interventions seem dependent on the cooling of peripheral blood, which circulates to the core (17); however, the neck only forms <10% of the body's surface area and therefore has limited potential to reduce core temperature. Brain temperature is more important than body temperature in the regulation of exercise (6), and it has been proposed that cooling the neck may decrease brain temperature because the brain is supplied by the carotid arteries within the neck (40). Although mathematical modeling articles have proposed that superficial cooling of the brain may be possible (40), clinical (30) and experimental (8,24) data have failed to identify a reduction in brain temperature after superior cooling. As a result, it seems unlikely that brain temperature was affected in the current study; however, this remains to be confirmed.

Previously, it was proposed that peripheral hormonal concentrations are important markers of exercise stress (4); however, more recently, it has been suggested that central, rather than peripheral, levels are key in regulating exercise performance in hot environments (20,27–29). Brisson et al. (4) suggested that the effects of a cooling intervention on the peripheral hormonal concentrations were magnitude dependent, but the data from the current study and that reported previously (35) show that cooling the neck has no effect on such concentrations even when the cooling is sustained and pronounced. Although there were no differences between trials, concentrations of dopamine and serotonin were both elevated at the end of the trial (90 min) compared with all other time points, replicating previous findings using a CC (35). The release of dopamine and serotonin is dependent on the intensity of the stress (in this case exercise) to which it is released in response to, and so significant differences were only observed after the most intense part of the trial—the 15-min time trial. The measurement of peripheral concentrations has been questioned because of the limited crossover with central concentrations (23,30–32), and the current study also highlights the issue of intraindividual variation and the importance of establishing participant-specific biological variance if such variables are to be measured. As with other similar investigations (27–29), this was not established in the current study; however, data suggest that such measures should be taken.

The improvements in performance observed in the current investigation were not matched with significant alterations in TS, FS, or RPE. The RPE results are different from those reported previously in a study of similar design (35) and also differ from those reported elsewhere recently after the administration of a menthol mouth rinse (21) and a dopamine reuptake inhibitor (37). The administration of a dopamine reuptake inhibitor reduced the impairment observed in time trial performance in a hot environment from −30% to −19% with the same RPE. The findings from Watson et al. (37) and Mundel and Jones (21) suggest that tolerance to hyperthermic exercise can be improved at the cortical level after alterations in sensation but also that exercise is limited by other mechanisms in addition to perception. This is tentatively supported in the current study by the assessment of pleasure and displeasure using the FS, which showed no differences with the cooling interventions despite altered performance replicating previous findings (34). Thermal sensation data differed from previous literature (35). In the current study, participants were required to differentiate the levels of thermal comfort they experienced at the neck from the rest of their body, and this was an additional measurement adopted in the present study compared with the previous (35). Thermal sensation of the neck was significantly reduced via the application of the CC compared with the NC trial and by the replacement of the CC compared with the NC and CC trials. It has been proposed that the neck is an optimal site for cooling because of its proximity to the thermoregulatory center (31); however, the extent to which cooling the neck affects perceived thermal states compared with cooling elsewhere has not been investigated. It has been established that the face is a site of high alliesthesial thermosensitivity and that cooling the face region results in a two- to fivefold greater suppression in thermal discomfort than cooling areas of the trunk and limbs (9) and so the neck may have similar qualities. It seems likely that the lack of difference in thermal comfort reported in this study is explained by the addition of data collection regarding the thermal sensation specific to the neck region and previous data reporting a combined thermal comfort. It is well documented that improvements in thermal sensation offer a benefit to exercise performed in a hot environment, and the data from the current study support the literature stating that head and neck cooling may offer a performance benefit (9,31,34). Interestingly, replacement of the CC did not improve performance in comparison to simply wearing the CC from the start despite a loss of cooling being observed in the CC trial and a lowered perception of thermal sensation being reported in $\mathrm{CC}_{\mathrm{replaced}}$, which suggests that there is a limit to the extent of deception and the beneficial effect of altered perception.

The performance benefit observed in the previous experimental study investigating the modified CC (35) was attributed to an up-regulation in the pace selected because of a positive alteration in the level of perceived thermal comfort. In the present study, there were no significant differences in the pacing strategy adopted. Participants initially adopted a faster pace in the $\mathrm{CC}_{\mathrm{replaced}}$ trial, but they were then unable to increase the pace selected as progressively as in the CC trial. These data suggest that the collar replacement may have provided a false signal, which resulted in the adoption of an initial pace in excess of what was sustainable, whereas the single application of the collar allowed for a progressive increase in pace during the performance test. The idea that the pacing strategy could be influenced by cooling the neck is due to the association between hyperthermia and the down-regulation of self-selected pace (19). It has been proposed that, during self-paced exercise, the intensity is regulated by a complex network of feedback and feed-forward systems regarding the physiological state of the body to allow for the completion of the task within homeostatic limits (19,32). Data from the current study and from a previous investigation using the same protocol (35) suggest that cooling the neck enhances preloaded time trial performance in a hot environment by masking the extent of the thermal strain; however, the present study suggests that there is a limit to the gain that can be achieved and to the extent to which the mechanisms that regulate exercise in the heat can be deceived. Interestingly, the gain was achieved despite relatively low final rectal temperatures (~38.90°C–38.97°C). Wearing a CC can enable greater tolerance of higher T_{rectal} (34), and so it is possible that the benefit to self-paced exercise could be greater still in more thermally challenging situations.

The critical core temperature and central governor theories are the two main theories proposed to explain the impairment in sporting performance observed in hot temperatures and both models propose that there are mechanisms in place to prevent the onset of a dangerously high internal temperature (12,19,32,36). Wearing a CC during hyperthermic exercise enables participants to tolerate higher levels of thermal and cardiovascular strain during exercise (34), and this has potential risks for user safety. Whereas other species have evolved mechanisms to safely tolerate high internal temperatures (e.g., selective brain cooling) (6), humans rely on the delicate balance between heat production and heat loss. It would be attractive to suggest that the data from the current study suggest a physiological, evolutional, or biochemical limit to the benefit of cooling due to the lack of a difference between CC and $\mathrm{CC}_{\mathrm{replaced}}$ trials; however, the lack of differences is more likely due to the nature of the test. There is a limit to the magnitude of an improvement, which can be observed in the time trial performance in a homogenous population. The fixed duration of a time trial dramatically improves the reliability of the test in comparison to an open-ended capacity test (15), but it does so by reducing the potential for variance to occur. As a result, there is also a limited potential for performance differences, and therefore, it is possible that the replaced collar may have a cumulative performance benefit in longer duration or open-loop tests.

CONCLUSIONS

Cooling the neck can improve time trial performance in a hot environment, although maintaining the neck at a reduced temperature via the replacement of a practical CC offers no additional benefit. Cooling the neck region does not alter the physiological or hormonal response to running exercise performed in high ambient temperatures; however, it does improve the subjective rating of thermal comfort, and this improvement in thermal comfort may improve performance by masking the thermal strain of the body.

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