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Self-paced exercise performance in the heat with neck cooling, menthol application, and abdominal cooling

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ABSTRACT

Objectives: To investigate whether the exercise performance benefits with neck cooling in the heat are attributable to neck-specific cooling, general body cooling, a cooler site-specific thermal perception or a combination of the above.
Design: Counter-balanced crossover design.
Methods: Twelve healthy participants cycled in the heat (34 °C, 30% relative humidity), at a power output (PO) self-selected to maintain a fixed rating of perceived exertion (RPE) of 16. Each participant underwent four experimental trials: no cooling (CON), neck cooling (NEC), abdominal cooling (ABD), or neck cooling with menthol (MEN). Participants cycled for 90 min or until their workload reduced by <70% of their initial PO. Changes in PO, rectal temperature (T_{re}), mean skin temperature (T_{sk}), whole-body thermal sensation (TS_{wb}) and thermal sensation of the neck (TS_{neck}) were recorded throughout.
Results: The mean reduction in PO throughout exercise was similar ($p = 0.431$) for CON (175 ± 10 W), NEC (176 ±12 W), ABD (172 ± 13 W) and MEN (174 ± 12 W). The ΔT_{re} at the end of exercise was similar ($p = 0.874$) for CON (0.83 ± 0.5 °C), NEC (0.85 ± 0.5 °C), ABD (0.82 ± 0.5 °C) and MEN (0.81 ± 0.5 °C). TS_{wb} was cooler ($p < 0.013$) in MEN (125 ± 8 mm) compared to CON (146 ± 19 mm), NEC (135 ± 11 mm) and ABD (141 ± 16 mm).
Conclusions: No differences in exercise performance or thermal strain were observed in any of the cooling trials compared to the CON trial, despite significantly cooler TS_{wb} values in the MEN and NEC trials compared to the CON trial. These findings differ from previous observations and highlight that the benefit of neck cooling may be situation dependent.

1. Introduction

Decrements in exercise performance in the heat, relative to cooler ambient temperatures, have long been recognised.[1] Behavioural thermoregulation contributes considerably to performance in the heat, whereby individuals down-regulate exercise intensity in an attempt to reduce internal metabolic heat production and dampen disruptions to thermal homeostasis.[2] During prolonged sporting events, reducing intensity is not desirable, therefore cooling strategies, such as water baths,[3] ice vests,[4] and cold towels,[5] applied before and during exercise are used to mitigate the development of heat-related performance decrements. Recently, neck cooling has been demonstrated to improve exercise performance in the heat,[6–8] however, the mechanisms responsible for these benefits remain equivocal.

As the thermoregulatory control centre resides in the brain, neck cooling collars have been suggested to improve exercise performance by cooling the carotid arteries, and consequently, the brain.[9] However, previous research which applied cooling coils of equivalent surface area to the neck and chest observed equal reductions in core temperature and sweat rate, suggesting no unique benefit was bestowed by neck cooling.[10] Similarly, the application of crushed ice packets to the neck, lowered arterial temperature but failed to widen the temperature difference between arterial and jugular-venous temperature, thereby indicating an inability to selectively cool the brain.[11] Taken together, these studies indicate, rather than brain cooling, the improved exercise performance with neck cooling may be due to general body cooling which is well known to improve exercise performance.[12]

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Finally, it is well known that local activation of cutaneous cold thermoreceptors caused by skin cooling results in a cooler thermal sensation and can cause consequent increases in exercise intensity due to improved thermal comfort.[13] Further, a similar effect has been observed with menthol application, a chemical compound which elicits a cooling sensation without affecting skin temperature by activating transient receptor potential channels (specifically TRPM8),[13] and has been shown previously to alter self-regulated performance.[14] Additionally, peripheral cutaneous thermosensors have demonstrated a greater influence towards behaviour during exercise in the heat compared to thermoneutral conditions.[15] Indeed, neck cooling has been demonstrated to locally cool skin and lower thermal sensation[6] and has been observed to improve time to exhaustion and distance travelled, independently from differences in core temperature.[7] Therefore, neck cooling may improve exercise performance simply by lowering whole-body and local thermal sensation.

Therefore, the purpose of this study was to determine the mechanism(s) responsible for improved exercise performance in the heat with neck cooling. To achieve this aim, four experimental trials were undertaken: (1) a control trial (CON), (2) a neck cooling trial (NEC), (3) applying a cooling collar to a region of the body equally or more thermally sensitive than the neck, which could not independently alter brain temperature [determined through preliminary testing to be the abdomen (ABD)], and (4) applying a cooling collar coated with a menthol gel to the neck in order to provide equal physical cooling as the NEC and ABD trials, while providing a greater local cooling sensation (MEN). As the MEN trial possessed both physical cooling and provided additional chemically-induced sensations of cooling, it was hypothesised exercise performance would be the greatest in this trial.

2. Methods

A sample size of 12 people was required for this study based on a power calculation (G*Power 3 software[16]), with an α of 0.05, a β of 0.05, and an effect size of 1.15 calculated from the difference in time to completion from a previous study employing a similar protocol.[17] Four females and eight males, all healthy non-smokers (age: 23 ± 3 years, mass; 72.7 ± 11.5 kg, height; 1.76 ± 0.07 m, VO_{2peak}; 50.3 ± 9.3 ml min^{-1} kg^{-1}) were recruited. Female participants were tested between days 2–8 of the menstrual cycle.[18] All trials were performed at the same time of day and participants refrained from caffeine, alcohol consumption and strenuous exercise 12 h prior to testing. The study was approved by the University of Sydney Research Ethics Board (HREC: 2016/517). All participants gave written informed consent and completed the Physical Activity Readiness Questionnaire (PAR-Q), and an American Heart Association (AHA) questionnaire.

To identify a skin region which was equally or more cold-sensitive as the neck, local thermosensory testing was conducted.[19] Using a thermode sensory analyser (Phystiemp Instruments Inc., NJ) a cold stimulus (14 °C) was applied to eight locations across the body (forearm, chest, posterior, lateral and anterior neck, the lateral and anterior abdomen, and the lower middle back). Participants rated their thermal sensation on a 200-mm visual analogue scale (VAS) as has been done previously,[19] ten seconds after application of each thermal stimulus. The VAS had the anchor points: very cold (0 mm), neutral (100 mm) and very hot (200 mm). Through this preliminary testing, it was determined the abdomen was more thermally sensitive than the neck (see Section 3) and therefore this location was used for the non-neck cooling trial (ABD).

Next, each participant completed a fixed-RPE familiarisation trial on an upright cycle ergometer (Excalibur Sport V 2.0 bicycle, Lode BV, The Netherlands). During this session, participants were taught how to interpret the RPE scale[20] and associate an RPE of 16 with an intensity between 'hard' and 'very hard'. The familiarisation trial involved the researcher selecting an initial power output (PO) of 80–100 W for the first 5 min, after which PO increased by 40–50 W every 5 min until an RPE of 16 was achieved. Participants were instructed to maintain an RPE of 16 by either increasing or decreasing their wattage for the next 10 min, and the average of this 10 min block established initial PO during the experimental trials. As in the experimental trials, participants were blinded to workload, exercise time and cadence.

Following the familiarisation session peak oxygen consumption (VO_{2peak}) of the participants was determined via expired gas analysis using a metabolic cart (Quark CPET, Cosmed, Asia Pacific PTY, Sydney Australia). Participants began cycling at the average PO established during the 16-RPE stage of the familiarisation protocol, with PO subsequently increased by 20 W min^{-1} until volitional exhaustion.[21]

Upon arrival to the laboratory, participants provided a urine sample, which was analysed for urine specific gravity (USG) with a refractometer (Reichert TS 400, Depew, NY). A USG of >1.020 was the cut-off criterion for euhydration.[22] Subsequently, participants were instrumented (described below) while resting in 25 °C and 30% relative humidity (RH) conditions. Following instrumentation, body mass measurements were taken, before a 20 min seated rest period in the experimental ambient conditions (34.4 ± 0.7 °C and 33 ± 1%RH).

Participants commenced cycling in front of a mechanised fan (Moretti, 45 cm high-speed, China), generating an air velocity of 4.0 m s^{-1} at the average external workload obtained during the 16-RPE stage of their familiarisation trial. Exercise intensity remained fixed for the first 5 min, after which participants were instructed to inform the researcher to change the ergometer resistance as needed to maintain an RPE of 16. Each time PO was adjusted, exercise time, heart rate and PO were recorded. Exercise was terminated after 90 min or if PO dropped <70% of initial workload. Participants were not permitted to ingest any water during the trials and no external motivation was provided.

In the NEC, ABD and MEN trials, a cooling collar (Black Ice LLC, Lakeland, TN dimensions: 375 mm × 60 mm × 15 mm) was applied to the neck or abdomen, secured to the participant with Velcro fastenings at the commencement of exercise and replaced every 20 min. Each collar was placed in the freezer at −1.3 °C, 2 h prior to testing, placed in temperate conditions 5 min prior to application, and were 2 °C upon application. In the MEN trial, 0.5 g of 4% concentration menthol gel (Dencorub Arthritis Ice Gel, Amcal) was applied across the collar. The experimental trials were counterbalanced with an incomplete design, and at least 48 h separated each trial.

Rectal temperature (T_{re}), oesophageal temperature (T_{es}) and aural canal temperature (T_{au}) was measured with general paediatric thermocouple probes (TM400, Covidien, Mansfield, Massachusetts, USA) continuously throughout the trial. Participants self-inserted the T_{re} probe ~12 cm beyond the anal sphincter. The T_{es} probe was inserted through the nasal cavity to a depth of 40 cm. The T_{au} probe was positioned against the tympanic membrane, then slightly withdrawn, and subsequently secured in place and insulated using cotton wool and ear defenders. A T_{au} value greater than T_{es} at rest was required prior to the start of exercise to confirm the probe was properly inserted within the ear canal. Skin temperature (T_{sk}) was measured at four sites by fixing heat-flux thermistors (Concept Engineering, Old Saybrook, Connecticut, USA) to the skin surface. Mean T_{sk} was expressed as an average of the four sites using the weighting of 30% (chest), 30% (arm), 20% (thigh), 20% (calf).[17] Additionally, in a subset of 7 participants, local skin temperature (T_{local}) was measured at the neck in all trials and on the abdomen in the ABD trial (ABD_{collar}) using 3 iButton™ temperature sensors (Maximum Integrated Products, San Jose, CA, USA) and was expressed as an unweighted mean.

Whole-body sweat loss was calculated by measuring the difference between body mass measurements immediately (~10 s) before and after exercise in triplicate on a platform scale (Mettler 1D1 Multirange; Germany; accuracy: ±2 g), and then corrected for trial duration to determine whole-body sweat rate (WBSR). Local sweat rate of the back (LSR_{back}) was measured continuously via a ventilated sweat capsule. Anhydrous air at a flow rate of 0.75 L/min passed through the capsule onto the skin surface. Using flow rate, air temperature and humidity of the effluent air, and sweat capsule surface area (4.0 cm^2), LSR_{back} was calculated and expressed in mg min^{-1} cm^{-2} (Series HMT333, Vaisala, Helsinki, Finland). Heart rate (HR) was recorded every 5 min during rest and exercise using 4-lead wireless electrocardiography (Quark T12x Asia Pacific PTY, Sydney Australia,) with electrodes (Foam Electrodes, Covidien, Mansfield, Massachusetts, USA).

Every 5 min during exercise, whole-body thermal comfort (TC_{wb}) was reported on a VAS with the anchor points: "very uncomfortable" (0 mm), "slightly uncomfortable" (50 mm), "neutral" (100 mm), "slightly comfortable" (150 mm) and "very comfortable" (200 mm). Whole-body thermal sensation (TS_{wb}) and local thermal sensation (TS_{local}) measured at the neck in all trials and the abdomen in the ABD trials only (ABD_{collar}) was reported on the same VAS utilised in the preliminary trial.

All data are expressed as a mean (±SD). A one-way repeated measures ANOVA with the repeated factor of trial (4 levels: CON, NEC, ABD, and MEN) was employed with the dependent variables of mean power output (MPO), trial duration, mean workload, total work completed, preliminary thermosensation and WBSR. Due to different trial durations, remaining outcome measures were compared and expressed in two different ways: across the initial 40 min of exercise (MIN), and as percentage of trial completion (PER). A two-way repeated measures ANOVA with the repeated factors of trial, and either exercise time (MIN, 9 levels: 0, 5, 10, 15, 20, 25, 30, 35 and 40 min) or trial completion (PER, 6 levels: 0, 20, 40, 60, 80 and 100%) was employed to analyse the dependent variables of reduction in MPO, work completed, T_{re}, T_{es}, T_{au}, T_{sk}, TS_{wb}, TS_{local}, TC_{wb}, HR and LSR_{back}. The dependent variables TS_{local} and T_{local} were analysed in an identical manner as the latter variables, except for trial had five levels (CON, NEC, ABD, MEN and ABD_{local}). Finally, in order to verify the familiarisation session was sufficient to prevent a learning effect, the main performance outcomes were analysed using a one-way repeated measures ANOVA with the repeated factor of trial order (4 levels: 1st, 2nd, 3rd and 4th trial). Additionally, to characterise the size of response of each variable, the effect size of each ANOVA was calculated and reported as an eta-squared value (η^2), where 0.01 is a small effect size, 0.09 is a medium effect size and 0.25 is a large effect size.[23] In the event of a significant main effect or interaction, post-hoc analyses were performed using a two-tailed paired t-test with a Holm-Bonferroni correction to maintain the probability of making a type 1 error at 5%. The effect size of each t-test was calculated and reported as Cohen's d (d), where 0.20 is a small effect size, 0.50 is a medium effect size and 0.80 is a large effect size.[23] All statistical analyses were performed using GraphPad Prism (version 6.0, GraphPad Software, La Jolla, CA).

3. Results

Thermosensory testing during the preliminary trial demonstrated differences between the chest (48 ± 28 mm), forearm (34 ± 16 mm), mean neck (42 ± 13 mm) and mean abdomen (28 ± 11 mm) for thermal sensation responses ($p = 0.040$, $\eta^2 = 0.321$). Specifically, the abdomen recorded a cooler thermal sensation than the neck ($p = 0.033$, $d = 1.156$); therefore, this location was selected for the non-neck cooling location.

No influence of intervention on trial duration ($p = 0.552$, $\eta^2 = 0.056$; Fig. 1A), MPO ($p = 0.395$, $\eta^2 = 0.073$; Fig. 1B), reduction in MPO (MIN: $p = 0.391$, $\eta^2 = 0.119$; PER: $p = 0.431$, $\eta^2 = 0.002$; Fig. 1C), mean total work completed ($p = 0.353$, $\eta^2 = 0.095$; Fig. 1D), reduction in work completed (MIN: $p = 0.378$, $\eta^2 = 0.119$; PER: $p = 0.353$, $\eta^2 = 0.002$; Fig. 1E), or the percentile reduction in MPO from initial workload (MIN: $p = 0.760$, $\eta^2 = 0.003$; PER: $p = 0.808$, $\eta^2 = 0.004$; Fig. 1F) was observed.

No main effect of trial-order was found for trial duration ($p = 0.068$, $\eta^2 = 0.219$), MPO ($p = 0.303$, $\eta^2 = 0.103$), reduction in MPO (MIN: $p = 0.664$, $\eta^2 = 0.001$; PER: $p = 0.706$, $\eta^2 = 0.001$), reduction in work completed (MIN: $p = 0.735$, $\eta^2 = 0.001$; PER: $p = 0.759$, $\eta^2 = 0.001$) or percentile reduction in MPO (MIN: $p = 0.203$, $\eta^2 = 0.012$; PER: $p = 0.463$, $\eta^2 = 0.009$). However, there was an effect on total work ($p = 0.010$, $\eta^2 = 0.335$). Specifically, a greater amount of total work was performed in the 3rd (656 ± 291 kJ; $p = 0.047$, $d = 0.339$) and 4th (660 ± 247 kJ; $p < 0.001$, $d = 386$) trials but not the 2nd trial (617 ± 221 W; $p = 0.248$, $d = 0.219$) compared to the first trial (568 ± 233 kJ).

The ΔT_{au} was similar between all trials (MIN: $p = 0.970$, $\eta^2 = 0.001$; PER: $p = 0.823$; Fig. 2A) as was ΔT_{re} (MIN: $p = 0.951$, $\eta^2 = 0.001$; PER: $p = 0.874$, $\eta^2 = 0.002$; Fig. 2B), ΔT_{es} (MIN: $p = 0.324$, $\eta^2 = 0.011$; PER: $p = 0.117$, $\eta^2 = 0.021$; Fig. 2C), ΔT_{sk} (MIN: $p = 0.562$, $\eta^2 = 0.020$; PER $p = 0.584$, $\eta^2 = 0.017$ Fig. 2D) and HR (MIN: $p = 0.136$, $\eta^2 = 0.017$; PER: $p = 0.094$, $\eta^2 = 0.024$; Fig. 2E). Conversely, intervention type did alter LSR_{back} (MIN: $p = 0.019$, $\eta^2 = 0.067$; PER: $p = 0.021$, $\eta^2 = 0.055$; Fig. 2F). Expressed as time, LSR_{back} was greater after 5 min of exercise in CON compared to MEN ($p < 0.006$, $d > 1.109$), after 10 min, LSR_{back} was greater in ABD than MEN ($p < 0.014$, $d = 0.753$), and after 15 min LSR_{back} was greater in CON compared to NEC ($p < 0.043$, $d > 0.511$) until the end of 40 min. Expressed as trial completion, LSR_{back} was greater in CON compared to MEN ($p < 0.022$, $d > 0.687$) after 40%, after 60% LSR_{back} was greater in CON compared to NEC ($p < 0.031$, $d > 0.611$). No differences in WBSR were observed (CON: 1101 ± 530 g min^{-1}; NEC: 1055 ± 484 g min^{-1}; ABD: 1146 ± 536 g min^{-1}; MEN: 1173 ± 435 g min^{-1}; $p = 0.342$, $\eta^2 = 0.095$).

An interaction between time and interventions for TS_{wb} was observed (MIN: $p = 0.013$, $\eta^2 = 0.020$; PER: $p = 0.001$, $\eta^2 = 0.032$; Fig. 3A). Expressed as time, MEN resulted in cooler TS_{wb} responses from 15 min to 40 min of exercise compared to CON ($p < 0.001$, $d > 0.684$). MEN resulted in cooler TS_{wb} responses compared to ABD from 20 min ($p < 0.016$, $d > 0.486$), and from 30 min NEC resulted in cooler TS_{wb} responses compared to CON ($p < 0.020$, $d > 0.633$) until 40 min of exercise. Expressed as trial completion, from 60% MEN resulted in cooler TS_{wb} responses compared to CON ($p < 0.001$, $d > 1.293$) and ABD ($p < 0.001$, $d > 0.690$). From 80% of trial completion, NEC resulted in cooler TS_{wb} responses compared to CON ($p = 0.002$, $d > 0.821$). There was a significant interaction between intervention for TS_{local} expressed both as time and trial completion (MIN: $p < 0.001$, $\eta^2 = 0.062$; PER: $p < 0.001$, $\eta^2 = 0.091$; Fig. 3B). Expressed as time, NEC and MEN were lower than CON, ABD, and ABD_{collar} (all $p < 0.001$, $d > 1.000$) from 5 to 40 min of exercise. Similarly, ABD_{collar} was lower than CON and ABD from 5 to 40 min of exercise (all $p < 0.05$, $d > 0.800$) with the exception of ABD_{collar} and ABD at 15 min ($p = 0.153$, $d = 0.600$). Further, MEN was lower than NEC from 15 to 40 min of exercise (all $p < 0.035$, $d > 0.453$). Expressed as trial completion, NEC and MEN were lower than CON, ABD, and ABD_{collar} (all $p < 0.030$, $d > 0.863$) from 20% to 100% of exercise. Similarly, ABD_{collar} was lower than CON and ABD from 20% to 80% of exercise (all $p < 0.012$, $d > 0.845$). Further, MEN was lower

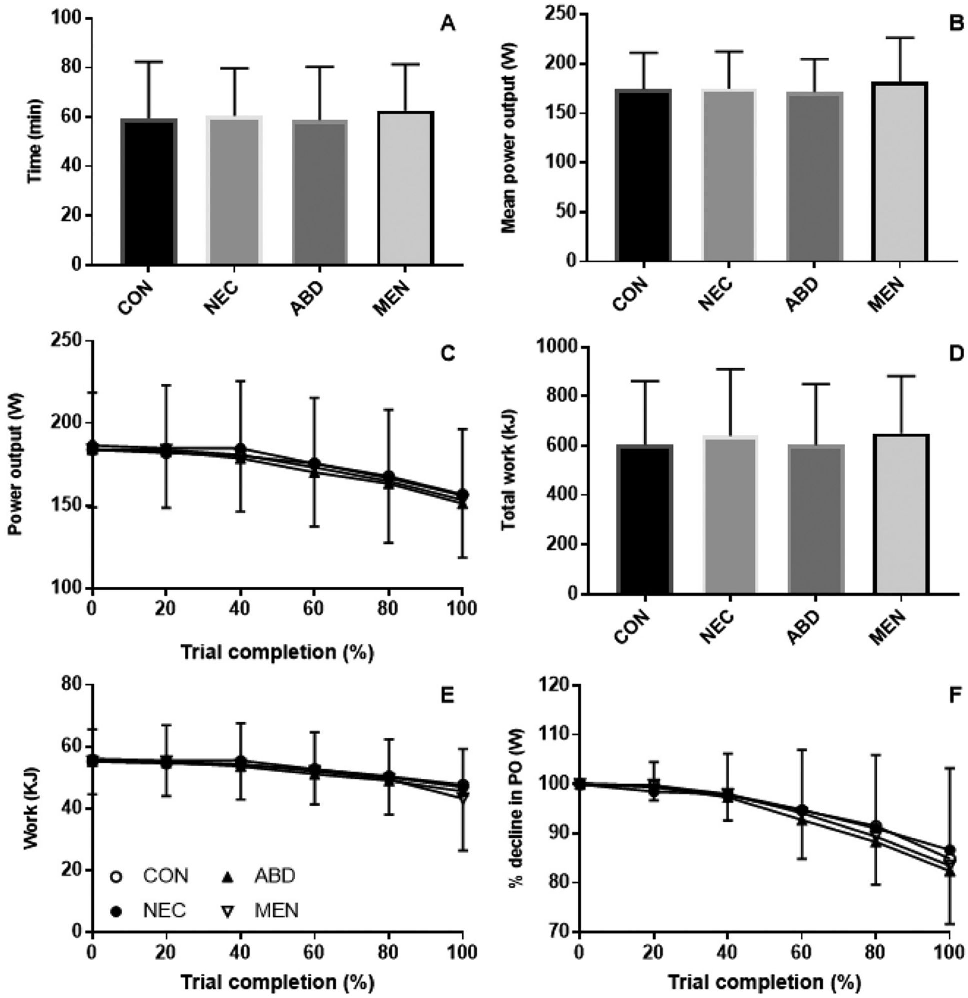

Fig. 1. Performance outcomes (±SD) for control (CON), neck cooling (NEC), abdominal cooling (ABD) and neck cooling with menthol (MEN). In alphabetical order, trial duration (A), mean power output (B), power output (C), total work completed (D), work completed (E) and decline in power output expressed as a percentage of initial power output (F).

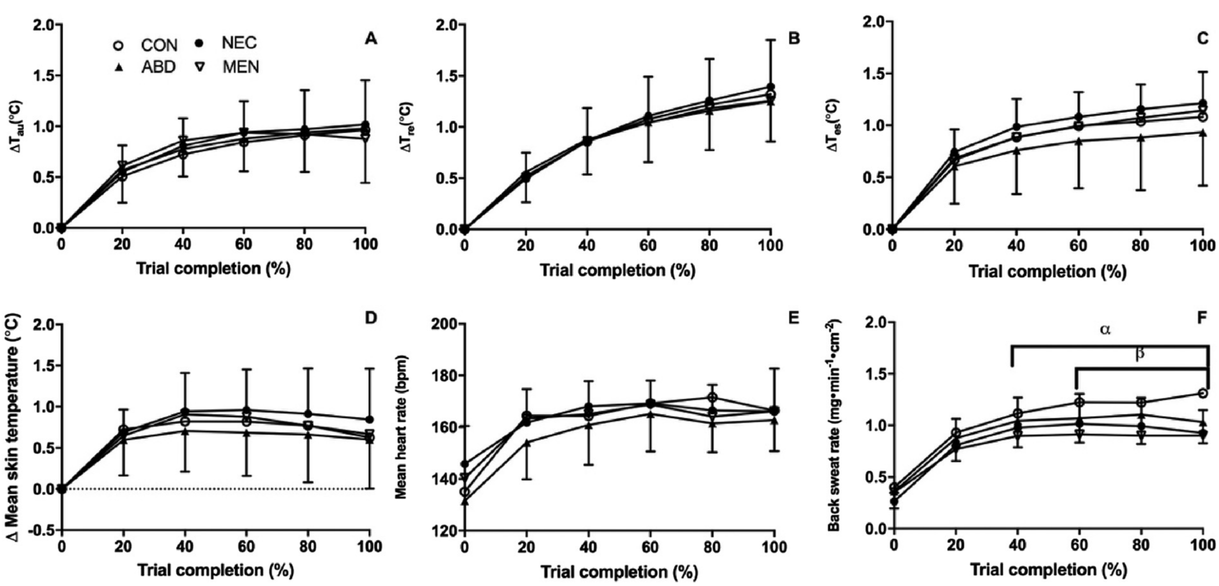

Fig. 2. Thermometric data and physiological changes (±SD) for control (CON), neck cooling (NEC), abdominal cooling (ABD) and neck cooling with menthol (MEN). Change in aural canal temperature (T_{au}) (A), change in rectal temperature (T_{re}) (B), change in oesophageal temperature (T_{es}) (C), change in mean skin temperature (D), change in heart rate (HR) (E) and change in back sweat rate expressed as percentage of trial completion (F) where α denotes CON > MEN (i.e. greater sweat rate) ($p < 0.022$), and β denotes CON > NEC ($p < 0.031$).

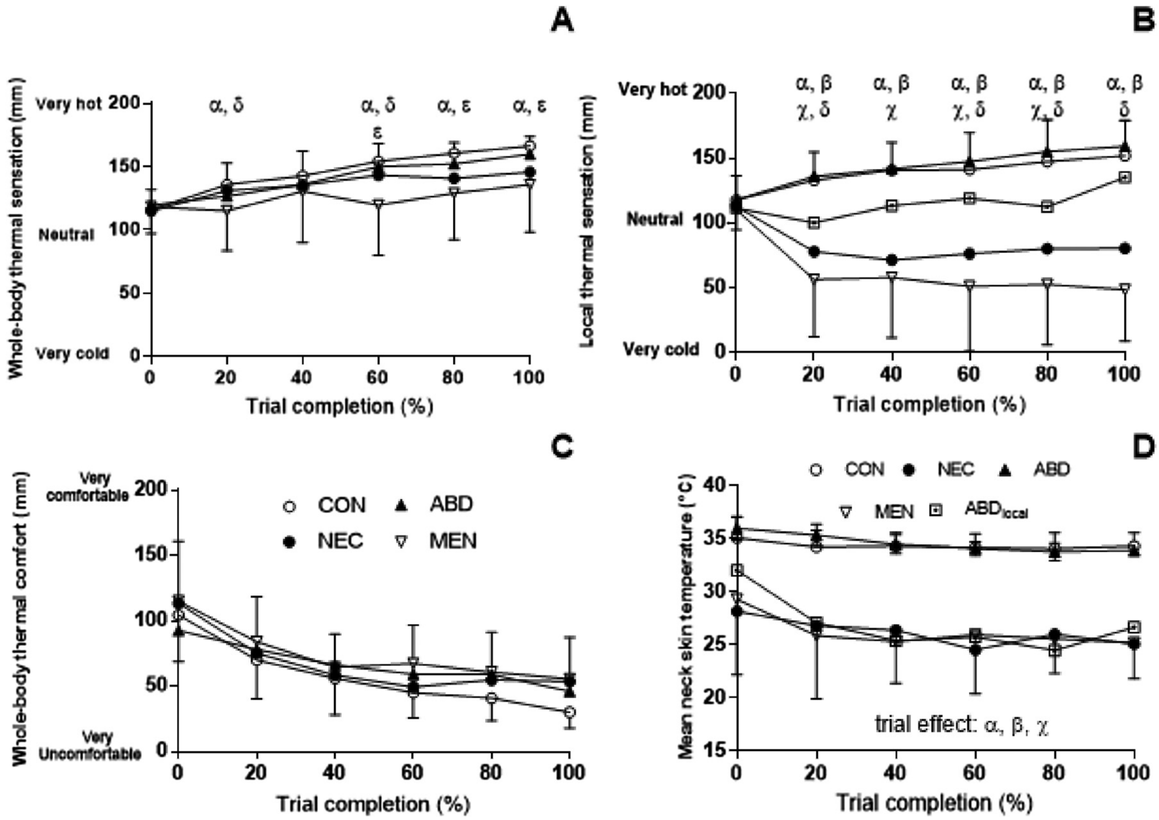

Fig. 3. In alphabetical order, whole-body thermal sensation (TS_{wb}; A), local thermal sensation (TS_{local}; B), whole-body thermal comfort (TC_{wb}; C) and local skin temperature (T_{local}; D; n = 7) for the control (CON), neck cooling (NEC), abdominal cooling (ABD), and neck cooling with menthol (MEN) trials. Panels B and D additionally display the TS_{local} and T_{local}, respectively, under the cooling collar in the ABD trial (ABD_{local}). All values are means (±SD). Differences are denoted as follows: α is MEN < CON&ABD, β is NEC < CON&ABD, χ is ABD_{local} < NEC&ABD, δ is MEN < NEC and ε is NEC < CON (all p < 0.050).

than NEC at 20% and from 60% to 100% of exercise (all $p < 0.015$, $d > 0.654$). No effect of intervention was identified for TC_{wb} (MIN: $p = 0.067$, $\eta^2 = 0.035$; PER: $p = 0.061$, $\eta^2 = 0.026$ Fig. 3C). In a subset of 7 participants, a main effect of intervention on T_{local} was identified (MIN: $p < 0.001$, $\eta^2 = 0.606$; PER: $p < 0.001$, $\eta^2 = 0.576$; Fig. 3D), wherein for both MIN and PER, T_{local} was lower in NEC, MEN and ABD_{collar} compared to CON and ABD (all $p < 0.001$, $d > 2.000$), but no other differences existed (all $p > 0.900$, $d < 0.200$).

4. Discussion

The current study sought to isolate the mechanism by which neck cooling improved exercise performance in the heat by testing three different types of cooling interventions compared to a control trial. Despite observing a cooler TS_{wb} in the MEN and NEC compared to the CON trial, none of the applied cooling interventions improved exercise performance or meaningfully altered core or skin temperature, compared to the CON trial. The lack of differences was unexpected as cooling collar application has been previously demonstrated to be beneficial towards exercise performance in the heat.[6,7] Indeed, the two novel types of cooling interventions theoretically had more potential to improve performance than traditional neck cooling. Therefore, the lack of performance benefit observed in the present study likely stemmed from the differences in the experimental conditions between the present and previous investigations, which are discussed below.

One potential explanation for the lack of improved performance is the present investigation was the only study to use a fixed-RPE protocol. A fixed-RPE protcol was selected because increases in T_{sk} and core temperature are well known to increase sensations of thermal discomfort, and consequently RPE.[12] Therefore, when participants are informed to adjust their PO so to not deviate from a set RPE of 16, an improved thermal perception should theoretically increase exercise intensity.[14] Indeed, previous studies investigating interventions affecting thermal behaviour have demonstrated the fixed-RPE protocol is sufficiently sensitive to detect differences.[14,24] As such, differences in thermal sensation and T_{sk} as a result of NEC, ABD and MEN in comparison to the CON trial should have resulted in changes in selected PO; although this was not observed. However, as thermal sensitivity to a cold stimulus is reduced during exercise,[25] perhaps the cooling power of the collars were insufficient to modify T_{sk} to an extent whereby thermal perception, and by association, the selected PO for a given RPE, were meaningfully altered.

Another possibility could be the level of heat stress in the present study was insufficient to observe differences in performance in the cooling trials. Previously, studies demonstrating a beneficial effect of neck cooling have been undertaken in more thermally stressful conditions, such as a treadmil test to exhaustion at 32.2 °C and 53%RH[6] or a 90 min preload treadmill time-trial conducted in ~30 °C and 50%RH.[7,8] While exercise preload protocols may be useful for increasing fatigue and core temperature to better observe performance differences, such scenarios may have limited real-world applicability.[26] As typical exercise bouts are initiated closer to core temperatures of ~37 °C rather than ~38.7 °C, we argue the present protocol may be more ecologically valid than previous protocols.

In the present study, T_{local} was significantly and equivalently lowered under the cooling collars for MEN, NEC and ABD_{collar} compared to the uncovered neck location in the CON and ABD trials, however, the corresponding local and whole-body ratings of thermal sensation between these trials differed significantly.

Specifically, in order of least warm to warmest sensation, the trial order for TS_{wb} was MEN, NEC, ABD then CON and MEN, NEC, ABD_{collar} then CON and ABD for TS_{local}. These findings demonstrate: (1) the application of menthol to a locally applied cooling intervention can elicit further cooling sensations and (2) despite a similar magnitude of cooling (as denoted by the similar changes in T_{local}) cooling the neck was more effective at eliciting a cooler whole-body thermal sensation than cooling the abdomen, despite the abdominal region being more thermally sensitive when tested at rest. The former finding is likely due to the well-known effect of menthol to lower the firing threshold for cool-sensitive thermoreceptors,[13] whereas the latter finding likely supports earlier work demonstrating that thermoreceptors near the facial and cranial regions have a greater relative influence on whole-body thermal sensation in the heat[27] as well as that, the relative contribution of thermally sensitive regions change from rest to exercise.[28] Additionally, LSR_{back} was significantly lower in the NEC and MEN compared to CON trial, despite no difference in WBSR. These apparently incongruent observations were possibly due to a local cooling effect, as has been previously demonstrated,[29] from the collar being in close proximity to the sweat capsule.

A trial-order effect for the total work performed was observed in the present study, with greater amounts of work completed in the 3rd and 4th trials compared to the 1st trial. This finding indicates one familiarisation session was likely insufficient to naturalise the participants to the study protocol. While this likely contributed to increased variability within the study, the study was counter balanced, therefore the augmented amount of variability was shared equally between the different interventions and should not have affected the end results. While the repeatability of time to exhaustion and time trial protocols have been firmly established[30] to the best of our knowledge the repeatability of RPE protocols has yet to be studied and studies in this area are warranted. Based on our trial order analyses, participants in future studies employing this type of protocol should undergo at least two familiarisation sessions prior to experimental testing.

Time constraints during data collection led to three primary limitations of the study. First, the thermosensory testing during pilot testing was conducted at rest. Previous research has demonstrated that regional thermosensitivity changes from rest to exercise[28] and this may account for why local thermal sensation of the abdomen was warmer than local thermal sensation of the neck, despite similar skin temperatures. Second, despite giving the participants a 20 min rest, the VO_{2peak} test was conducted after the RPE familiarisation session, and therefore participants may have tired prematurely, thereby underestimating their true VO_{2peak}. Third, as discussed above, the number of familiarisation sessions were likely insufficient for completely eliminating a learning effect. Finally, as the present study differed from previous studies both in the trial type (RPE clamp) and the thermal status (no-preload compared to preload phase) future studies should be conducted wherein cooling collars are applied during a time-trial in the heat without a preload period or else outdoors under actual time-trial conditions.

5. Conclusion

Contrary to initial expectations, neither exercise performance nor thermal strain were affected by the application of cooling collars to the abdomen or neck, with or without menthol application, compared to a control trial. This lack of benefit to exercise performance and body temperatures occurred despite cooler local and whole-body thermal perception with the application of cooling collars with and without the application of menthol. However, these findings do question the potential effectiveness of neck cooling for improving exercise performance under ecologically valid conditions, and therefore, further research is warranted.

Practical implications

- Cooling collars may not be effective at improving self-paced exercise performance in the heat.
- Neck cooling collars make people feel cooler during self-paced exercise in the heat.
- Adding menthol to cooling collars make people feel even more cool.
- Adding menthol to other cooling interventions will likely improve thermal cooling sensation.

Acknowledgements

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Appendix A.

List of abbreviations

ABD	Abdomen cooling trial
CON	No cooling trial
LSR_{back}	Local sweat rate of the back
MEN	Neck cooling with menthol trial
NEC	Neck cooling trial
ABD_{collar}	Under the collar in abdominal trial
RPE	Rate of perceived exertion
T_{au}	Aural canal temperature
TC_{wb}	Whole-body thermal comfort
T_{es}	Oesophageal temperature
T_{re}	Rectal temperature
T_{sk}	Skin temperature
TS_{wb}	Whole-body thermal sensation
T_{local}	Local skin temperature
TS_{local}	Local thermal sensation
VAS	Visual analogue scale
WBSR	Whole-body sweat rate
PO	Power output
MPO	Mean power output

References

1. Galloway SD, Maughan RJ. Effects of ambient temperature on the capacity to perform prolonged cycle exercise in man. *Med Sci Sports Exerc* 1997; 29(9):1240–1249.
2. Flouris AD, Schlader ZJ. Human behavioral thermoregulation during exercise in the heat. *SJMSS* 2015; 25(S1):52–64.
3. Vaile J, Halson S, Gill N et al. Effect of cold water immersion on repeat cycling performance and thermoregulation in the heat. *J Sports Sci* 2008; 26(5):431–440.
4. Cotter JD, Sleivert GG, Roberts WS et al. Effect of pre-cooling, with and without thigh cooling, on strain and endurance exercise performance in the heat. *Comp Biochem Physiol A Mol Integr Physiol* 2001; 128(4):667–677.
5. Schranner D, Scherer L, Lynch GP et al. In-play cooling interventions for simulated match-play tennis in hot/humid conditions. *Med Sci Sports Exerc* 2017; 49(5):991–998.
6. Tyler CJ, Sunderland C. Cooling the neck region during exercise in the heat. *J Athl Train* 2011; 46(1):61–68.
7. Tyler CJ, Sunderland C. Neck cooling and running performance in the heat: single versus repeated application. *Med Sci Sports Exerc* 2011; 43(12):2388–2395.
8. Tyler CJ, Wild P, Sunderland C. Practical neck cooling and time-trial running performance in a hot environment. *Eur J Appl Physiol* 2010; 110(5):1063–1074.
9. Zhu L. Theoretical evaluation of contributions of heat conduction and countercurrent heat exchange in selective brain cooling in humans. *Ann Biomed Eng* 2000; 28(3):269–277.
10. Shvartz E. Effect of neck versus chest cooling on responses to work in heat. *J Appl Physiol* 1976; 40(5):668–672.

11. Nybo L, Wanscher M, Secher NH. Influence of intranasal and carotid cooling on cerebral temperature balance and oxygenation. *Front Physiol* 2014; 5.
12. Schlader ZJ, Simmons SE, Stannard SR et al. Skin temperature as a thermal controller of exercise intensity. *Eur J Appl Physiol* 2011; 111(8):1631–1639.
13. Montell C, Caterina MJ. Thermoregulation: channels that are cool to the core. *Curr Biol* 2007; 17(20):R885–R887.
14. Schlader ZJ, Simmons SE, Stannard SR et al. The independent roles of temperature and thermal perception in the control of human thermoregulatory behavior. *Physiol Behav* 2011; 103(2):217–224. http://dx.doi.org/10.1016/j.physbeh.2011.02.002.
15. Cabanac M, Cunningham DJ, Stolwijk JA. Thermoregulatory set point during exercise: a behavioral approach. *J Comp Physiol Psychol* 1971; 76(1):94–102.
16. Faul F, Erdfelder E, Lang A-G et al. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods* 2007; 39(2):175–191.
17. Ravanelli NM, Cramer MN, Molgat-Seon Y et al. Do greater rates of body heat storage precede the accelerated reduction of self-paced exercise intensity in the heat? *Eur J Appl Physiol* 2014; 114(11):2399–2410.
18. Gagnon D, Kenny GP. Sex differences in thermoeffector responses during exercise at fixed requirements for heat loss. *J Appl Physiol* 2012; 113(5):746–757.
19. Filingeri D, Fournet D, Hodder S et al. Body mapping of cutaneous wetness perception across the human torso during thermo-neutral and warm environmental exposures. *J Appl Physiol* 2014; 117(8):887–897.
20. Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc* 1982; 14(5):377–381.
21. CSEP. *Canadian Society for Exercise Physiology: Certified Fitness Appraiser: Resource Manual*, Ottawa, ON, Canada, CSEP, 1986.
22. Cheuvront SN, Ely BR, Kenefick RW et al. Biological variation and diagnostic accuracy of dehydration assessment markers. *Am J Clin Nutr* 2010; 92(3):565–573.
23. Cohen J. A power primer. *Psychol Bull* 1992; 112(1):155–159.
24. Tucker R, Marle T, Lambert EV et al. The rate of heat storage mediates an anticipatory reduction in exercise intensity during cycling at a fixed rating of perceived exertion. *J Physiol (Lond)* 2006; 574(Pt 3):905–915. http://dx.doi.org/10.1113/jphysiol.2005.101733.
25. Ouzzahra Y, Havenith G, Redortier B. Regional distribution of thermal sensitivity to cold at rest and during mild exercise in males. *J Therm Biol* 2012; 37(7):517–523.
26. Stevens CJ, Dascombe BJ. The reliability and validity of protocols for the assessment of endurance sports performance: an updated review. *Meas Phys Educ Exerc Sci* 2015; 19(4):177–185.
27. Arens E, Zhang H, Huizenga C. Partial- and whole-body thermal sensation and comfort—part I: uniform environmental conditions. *J Therm Biol* 2006; 31(1–2):53–59. http://dx.doi.org/10.1016/j.jtherbio.2005.11.028.
28. Gerrett N, Ouzzahra Y, Redortier B et al. Female thermal sensitivity to hot and cold during rest and exercise. *Physiol Behav* 2015; 152:11–19.
29. Wingo JE, Low DA, Keller DM et al. Skin blood flow and local temperature independently modify sweat rate during passive heat stress in humans. *J Appl Physiol* 2010; 109(5):1301–1306. http://dx.doi.org/10.1152/japplphysiol.00646.2010.
30. Jeukendrup A, Saris WH, Brouns F et al. A new validated endurance performance test. *Med Sci Sports Exerc* 1996; 28(2):266–270.