

Title: Relieving thermal discomfort: effects of sprayed L-Menthol on perception, performance and time trial cycling in the heat

MJ. Barwood^{1*}, J. Corbett², K. Thomas¹ & P. Twentyman¹

¹Department of Sport, Exercise and Rehabilitation

University of Northumbria

Northumberland Building

Northumberland Road

NE1 8ST

Tel: +44 (0)191 227 3717

Fax: +44 (0)191 227 3519

Email: martin.barwood@northumbria.ac.uk

²Department of Sport and Exercise Science

University of Portsmouth

Spinnaker Building

Cambridge Road

PO1 2ER

*Corresponding author

Running head: Menthol, perception, pacing & TT performance

Abstract

Aim: L-Menthol stimulates cutaneous thermoreceptors and induces cool sensations improving thermal comfort but has been linked to heat storage responses; this could increase risk of heat illness during self-paced exercise in the heat. Therefore, L-Menthol application could lead to a discrepancy between behavioural and autonomic thermoregulatory drivers. **Method:** Eight male participants volunteered. They were familiarised and then completed two trials in hot conditions (33.5°C, 33% RH) where their t-shirt was sprayed with CONTROL-SPRAY or MENTHOL-SPRAY after 10 km (i.e. when they were hot and uncomfortable) of a 16.1 km cycling time trial (TT). Thermal perception (thermal sensation & comfort; TS, TC), thermal responses (rectal temperature [T_{rec}], skin temperature [T_{skin}]), perceived exertion (RPE), heart rate, pacing (power output) and TT completion time were measured. **Results:** MENTHOL-SPRAY made participants feel cooler and more comfortable and resulted in lower RPE (i.e. less exertion) yet performance was unchanged (TT completion: CONTROL-SPRAY 32.4 [2.9] & MENTHOL-SPRAY 32.7 [3.0] minutes). T_{rec} rate of increase was 1.40 [0.60] and 1.45 [0.40] °C·hr⁻¹ after CONTROL-SPRAY and MENTHOL-SPRAY application which were not different. **Conclusions:** Spraying L-MENTHOL toward the end of self-paced exercise in the heat improved perception but didn't alter performance and did not increase heat illness risk.

Keywords

Thermoregulation, behaviour, sensation, perceived exertion

Introduction

Exercise performance in hot conditions is impaired compared to cooler climates (Tucker et al. 2006). Consequently in hot conditions, fatigue occurs earlier and exercise capacity during fixed or self-paced activity is reduced (Galloway & Maughan, 1997; Tucker et al. 2004). The aetiology of this fatigue is multi-faceted and is probably task dependent (Nybo et al. 2014) but broadly encompasses aspects of motivation (Marcora & Staiano, 2010), the occurrence of hyperthermia (Nybo & Nielsen., 2001) and raised skin temperature (Sawka et al. 2012), cardiovascular strain (Rowell et al. 1966), neuromuscular changes within the central nervous system (Nybo & Nielsen. 2001) and an altered metabolic profile in the activity dependent muscle groups (Parkin et al. 1999). The conscious culmination of disproportionate challenge to homeostasis in any of these regulatory systems is an increase in the rating of perceived exertion (RPE) and a resultant reduction in self-selected exercise pace (St Clair Gibson & Foster, 2007). Consequently, any intervention that results in lowered perceived exertion at a given work rate is thought to have the potential to be performance enhancing (De Koning et al. 2011). However, RPE is not the only conscious sensation to be influenced by a hyperthermic exercise bout. A change in the rate of increase in thermal comfort and sensation and the absolute rating achieved is also synonymous with exercise in hot conditions (Schlader et al. 2011) leading to the suggestion that the early onset of fatigue is also associated with the sensation of feeling hot and uncomfortable (Marcora, 2007). Accordingly, interventions that reduce the extent of the disturbance in thermal perception may also influence performance (Schlader et al. 2011).

The application of L-menthol to the skin stimulates cool sensations mediated by specialized sensory neurons (Jordt et al. 2003). These neurons feature a highly sensitive receptor, TRPM8, which is activated by temperatures ranging from 8 to 28 °C (Jordt et al. 2003), and by chemical compounds such as L-menthol (McKemy et al. 2002; Peier et al. 2002). Body sprays comprising a relatively low concentration of L-Menthol (0.05 to 0.80 % L-Menthol in solution) have been shown to induce improvements in thermal sensation and comfort during

fixed intensity (Gillis et al. 2010 [0.05 & 0.20 % L-Menthol]; Lee et al. 2012 [0.80 % L-Menthol]) and self-paced exercise (Barwood et al. 2011 & 2014 [0.05 % & 0.20 % L-Menthol]) in the heat and have been marketed as performance enhancing in combination with dissolved alcohol at low concentrations (e.g. Physicool™, London, U.K; 0.20 %). However, independent experimental evidence in support of the ergogenic effect of L-Menthol has yet to be identified (Barwood et al. 2014). It is possible that this null effect is due the timing of the application of the menthol solution immediately before the start of exercise (i.e. 40 km time trial (TT) in 32°C heat; Barwood et al. 2011). In these experiments thermal perception was improved (toward being cooler and more comfortable) but thermal comfort was still high (i.e. not yet uncomfortable) at this stage of the exercise bout and there was no effect on performance (Barwood et al. 2011). Later experiments attempted to induce thermal discomfort with a thermal pre-load prior to the start of a TT following which L-Menthol was applied; yet performance remained unaffected (Barwood et al. 2014). This is surprising given that, under more extreme experimental conditions (55°C solution perfused through a liquid conditioned garment) and exercise protocols (an RPE clamp protocol), thermal perception has been shown to drive exercise behaviour (Schlader et al. 2011). Schlader and colleagues (2011) showed that their exercise task was impaired or enhanced depending on the sensation they induced by chemically stimulating the skin. In this study Schalder et al (2011) applied either capsaicin or a high concentration of L-Menthol gel (8%) to the face and induced hot and cool thermal sensations respectively. These data are valuable yet the extremes of their experiment and the nature of the exercise task (i.e. an RPE clamp protocol) do not accurately describe what may prevail in the real life sporting setting. Accordingly, it seems logical, but as yet untested, that L-Menthol spray could improve thermal perception, alter pacing and improve performance when thermal discomfort would otherwise be impairing performance.

It is important to establish whether L-Menthol spray is in fact beneficial to exercise performance in the heat as its application is not without potential negative health

consequences. Previous experiments have suggested that L-Menthol application (0.2 % L-Menthol per 100 mL solution) can significantly increase the rate at which deep body temperature rises culminating in a higher absolute deep body temperature at the end of a 60-minute constant load exercise bout (Gillis et al. 2010). Although the extent of the difference was small (never more than 0.2°C) it does seem that this response could increase the risk of heat illness. Gillis and colleagues (2010) concluded that the 0.20 % L-Menthol concentration evoked vasoconstriction in a similar manner to a cold challenge to the skin thereby reducing cutaneous blood flow and heat loss at the skin. Lee et al (2012) subsequently supported this effect using a 0.80 % L-Menthol spray in firefighters wearing protective clothing. In a previous experiment, we found no evidence that deep body temperature increased at a faster rate after L-Menthol was applied immediately before the start of self-paced exercise (Barwood et al. 2011) but this might not remain the case when L-Menthol is applied toward the end of exercise when maximal vasodilatation at the skin is more likely (Charkoudian, 2010) and the consequent effects of vasoconstriction for deep body temperature may be more marked. In conjunction with the altered thermal perceptual effects, we speculate that L-Menthol application could produce a conflict in behavioural and autonomic thermoregulatory drivers of exercise performance in the heat.

Accordingly, we sought to examine whether the application of 0.20 % L-Menthol to the t-shirt covering the torso towards the end of a self-paced exercise bout (i.e. when participants were already thermally uncomfortable and hyperthermic) induced improved thermal perception and altered self-selected power output during a 16.1 km TT in hot conditions (34°C, 35% RH); we hypothesised it would (H₁). We also sought to examine whether L-Menthol altered the rate of deep body temperature rise after application, we hypothesised it would (H₂), potentially culminating in a greater risk of heat illness.

Materials and Methods

Participants

The protocol was approved by the Northumbria University Research Ethics Committee. Eight healthy males (age 21 [2] yrs; height 1.81 [0.07] m; mass 83.10 [11.10] kg; surface area 2.03 [0.14]m²; Dubois & Dubois, 1916) volunteered to participate and provided written informed consent. The participants were physically active and accustomed to maximal exercise but were not trained cyclists *per se*. They abstained from alcohol, caffeine consumption and strenuous exercise 24 hours prior to each test and were non-smokers.

Experimental Design

The study used a within participant, double-blind, repeated-measures design. Participants first completed a familiarisation 16.1 km TT followed by counter-balanced completion of two further TTs in CONTROL-SPRAY and MENTHOL-SPRAY treatment conditions. All trials took place on separate days at the same time of day (\pm 1 hour) with a minimum of 48 hours between tests.

Description of Sprays

Sprays were produced by an independent chemical consultant (Chemical Associates, Rosemead, Frodsham, United Kingdom). The CONTROL-SPRAY contained 3% surfactants mixed in water, while the MENTHOL-SPRAY contained a concentration of 0.20 wt/wt L-Menthol in 3% surfactants plus water. In order to minimise supplementary perceptual cooling associated with a spray temperature lower than exercising skin temperature and ambient temperature, the bottles containing the sprays were immersed in a temperature controlled water bath held at 34°C within the chamber (Tempette Junior TE 8J, Techne, Cambridge, U.K), 1-hour before the trial commenced. The bath temperature was verified by a calibrated thermistor (Grant Instruments, Cambridge [Shepreth], Cambridge, U.K) immersed in the water throughout the test period. The agreement between bath temperature and spray temperature was checked in pilot tests prior to the commencement of the main trials and was assumed to be similar thereafter.

Procedure

Following arrival at the laboratory participants voided, and naked body mass was measured (Seca, Model 705 2321009, Vogel & Halke, Hamburg, Germany; accurate to 5 grams). Prior to dressing, participants were instrumented with a calibrated, insulated rectal thermistor (Grant Instruments Ltd, Cambridge [Shepreth], U.K) inserted (in private) 12-15 cm beyond the anal sphincter. Participants were also instrumented with skin thermistors (Grant Instruments Ltd, Cambridge [Shepreth], U.K) taped in place by surgical tape (Transpore™, 1527-1, 3M Health Care, MN, USA) at six different sites (Grant Instruments Ltd, Cambridge [Shepreth], U.K) and a heart rate monitor to measure cardiac frequency (f_c ; FT1, Polar Electro Oy, Kempele, Finland). Rectal temperature (T_{rec}) and skin temperature (T_{skin}) were logged automatically every 30-seconds using a remote data logger (Squirrel 2020 series, Grant Instruments Ltd, Cambridge [Shepreth], U.K). These data were used to calculate mean T_{skin} according to the equation of Olesen (1980) using an adapted weighted average of skin temperature at the bicep, chest, subscapular, forearm, thigh and calf and subsequently mean body temperature (T_b) according to the equation of Hardy & Dubois (1938).

Participants wore the same socks, cycling shorts, shoes and close-fitting, long sleeve t- shirt (the latter was sized to fit and was provided by the experimenters; 100 % polyester; Campri Sports Baselayer, Sportsdirect, Shirebrook, U.K) on each occasion. Participants entered an environmental chamber set to a dry bulb temperature of $\sim 33.5^\circ\text{C}$ and 33 % RH, which was measured every 5-minutes by a wet-bulb, globe, temperature (WBGT) station (1000 series, Squirrel Data Logger, Grant Instruments Ltd, Cambridge [Shepreth], U.K). Participants completed a standardised warm-up of 100 W at a cadence of 70 rpm for 5-minutes on the cycle ergometer (Velotron, Racermate, Seattle, USA). They were then given a further 3-minutes to stretch before remounting the ergometer. Prior to commencing the TT participants were reminded that they should complete the 16.1 km TT as quickly as possible and make a maximal effort. The TT course was a 16.1 km flat design constructed using the Velotron Racermate software. Participants received only feedback of distance progress

throughout the TT and were able to modulate intensity through variations in cadence and use of an electronic gearing system. Split time and power outputs were recorded at a frequency of 32 Hz using the Velotron software. Power data were filtered in to 1 s averages and were used to calculate mean power output. At the start of the exercise period a fan positioned 80 cm from the participants (Wahl, Model ZX220, Wahl, Sterling, IL, USA) and pointed in the direction of the participants' torso, was switched on. The wind speed produced by the fan was verified at a fixed position, in the middle of the top tube of the Velotron cycle ergometer, before and after the experiment by an anemometer (LM-8000 Anemometer, Digital Instruments, New York, USA; this approximated 2 to 2.5 m.s⁻¹). Participants were permitted to consume water *ad libitum* throughout the trial (water temperature ~19 °C).

Perceptual responses including RPE (Borg, 1982), thermal comfort (TC) and thermal sensation (TS & TC from Zhang, 2003; please refer to figures 1 & 2 for the worded descriptors anchoring these scales) were obtained at the start of the TT and on the completion of every 2 km of the TT. On completion of the 10th kilometre of the TT the participants' jersey was sprayed evenly with 100 mL of either the CONTROL-SPRAY or the MENTHOL SPRAY, whilst the participants continued to exercise. Spray volume was carefully measured on each occasion using calibrated, digital, weighing scales (Sartorius Mechatronics UK Ltd, TE6100, Surrey, U.K; accurate to 1 gram). Spraying took approximately 3-minutes and was performed using the same technique and by the same experimenter. The timing of the spray was designed to ensure the TT could be completed within the chemically active period of the MENTHOL-SPRAY (~20 minutes; Gillis et al. 2010) and at a point where the participants had become hot and uncomfortable; the latter was verified by perceptual data from the familiarisation trial.

Upon completion of the TT, all data logging systems were stopped and the participant exited the chamber. Thereafter, the participant was weighed naked and, in conjunction with measured fluid intake (Sartorius Mechatronics UK Ltd, TE6100, Surrey, U.K), sweat

production was calculated. The performance times of the participants were not revealed until the post-experiment debrief.

Data Analyses

Mean (SD) were calculated for: perceptual variables (RPE (not examined at rest), TC and TS), thermal and cardiovascular variables (T_{sk} , T_{rec} , T_{body} , and f_c) and performance variables (1 km average power output and TT completion time). The normality of distribution was checked using Kolmogorov Smirnov analyses. Subsequently, comparisons were made within participant, between conditions and across 1 km intervals for performance variables and 2 km intervals in the remaining variables using repeated measures ANOVA. Statistically significant effects were determined *post-hoc* using pairwise comparisons with a Bonferroni correction. Confidence intervals are also reported for TT completion data to a 95% level.

In order to examine whether the application of L-Menthol culminated in a different rate of rise in deep body temperature, the rate of rise in rectal temperature ($^{\circ}\text{C}\cdot\text{hr}^{-1}$) was calculated before and after spray application. These data were subsequently compared between condition using paired samples t-test. Comparisons were also made between spray manipulations using a paired samples t-test for fluid consumption, sweat production, environmental conditions, water bath temperature and spray volumes. The alpha level for all statistical tests was set at 0.05. Data analysis was conducted using PASW version 18 (SPSS Inc, Chicago, Illinois).

Results

Environmental Conditions

The environmental temperature (dry bulb) simulated during the tests was stable and averaged 33.3°C [0.3] °C and 33.5°C [0.5] °C in the CONTROL-SPRAY and MENTHOL-SPRAY conditions respectively and was not different between conditions ($t = -.977$, $p = .361$). The calculated RH was also stable and averaged 33 [6] % and 33 [5] % in the CONTROL-SPRAY and MENTHOL-SPRAY conditions respectively.

Perceptual Responses

Participants' thermal sensation responses were similar in each TT between 0 and 10 km (*i.e.* immediately before participants were sprayed) increasing steadily as the time trial progressed. The TS rating prior to spraying averaged 16.8 [1.1] cm and 17.0 [1.1] cm in the CONTROL-SPRAY and the MENTHOL-SPRAY conditions respectively and were not different between conditions ($p = .322$). They corresponded to the worded descriptor '*hot*'. At the 12 km time point, 4.13 [0.34] minutes after spraying (between trial mean [SD]), thermal sensation was significantly lower (main effect for condition: $F_{(1,7)} = 10.432$, $p = .014$ and interaction effect: $F_{(8,56)} = 11.487$, $p = .001$) in the MENTHOL-SPRAY (10.8 [3.0] cm) condition compared to the CONTROL-SPRAY (15.9 [1.4] cm; $p = .004$) which was unchanged ($p = .980$). These ratings corresponded to the worded descriptors '*warm*' to '*hot*' in the CONTROL-SPRAY and '*neutral*' in the MENTHOL-SPRAY condition. The differences in TS between condition were maintained throughout the remainder of the TT (14 km, $p = .006$; 16 km, $p = .025$); see figure 1 panel A.

****INSERT FIGURE 1 NEAR HERE****

The TC response reflected that of TS being very similar in each condition up to 10 km ($p = .238$) point where they averaged 8.4 [4.5] cm and 9.1 [4.4] cm in the CONTROL-SPRAY and MENTHOL-SPRAY condition corresponding to the worded descriptor '*just uncomfortable*'. After spraying was conducted TC responses were significantly higher (*i.e.* improved comfort;

main effect for condition: $F_{(1,7)} = 7.065$, $p = .033$ and interaction effect: $F_{(8,56)} = 3.725$, $p = .001$) at the 12 km ($p = .039$), and 16 km ($p = .023$) distance point in the MENTHOL-SPRAY relative to the CONTROL-SPRAY and approached significance at 14 km ($p = .055$).

At the 12 km distance point the TC rating averaged 9.5 [4.6] cm and 12.5 [3.7] cm in the CONTROL-SPRAY and MENTHOL-SPRAY respectively which most closely corresponded to the worded descriptors '*just uncomfortable*' and '*just comfortable*'. The TC at this point in the CONTROL-SPRAY condition transiently lowered at 12 km ($p = .017$) but returned to being similar to the pre-spray level at 14 km ($p = .485$) and 16 km ($p = .200$). The mean [SD] TC response across the TT in each condition is displayed in figure 1 panel B.

The RPE data showed evidence of a linear increase in both spray conditions (main effect for distance: $F_{(7,49)} = 26.120$, $p = .001$) up to the 10 km distance marker ($p = .980$) which averaged 15 [2] in each condition and corresponded to the descriptor '*hard*'. Thereafter, the application of the MENTHOL-SPRAY elicited a reduction in RPE compared to the CONTROL-SPRAY (interaction effect between condition and distance: $F_{(7,49)} = 2.447$, $p = .031$) nearing significance at 12 km ($p = .086$) and being significantly lower at 14 ($p = .038$) and 16 km ($p = .018$) in the MENTHOL-SPRAY condition. The mean [SD] difference across these distance markers was 1 [0] points on the RPE scale; but this did not produce a main effect for condition, $F_{(1,7)} = 2.681$, $p = .146$). RPE data across each TT are shown in figure 1 panel C.

****INSERT FIGURE 3 NEAR HERE****

Time Trial Performance

TT completion time was 32.4 [2.9] minutes and 32.7 [3.0] minutes in the CONTROL-SPRAY and MENTHOL-SPRAY conditions respectively which were not different ($t = .664$, $p = .528$). This equated to a mean power output of 164 [32] W and 161 [12] W which also were not

different ($t = .628$, $p = .550$; see figure 4). The pattern of the power output was very similar throughout the TT and showed no evidence of deviation as a consequence of the MENTHOL or CONTROL-SPRAY (no main effect for condition: $F_{(1,7)} = .146$, $p = .713$ or interaction $F_{(15,105)} = 1.071$, $p = .392$). The power output profile remained tightly regulated (see figure 2) across participants and distance points throughout the respective TTs even after spraying. The estimated average speed produced from this power profile was $30.3 [2.0] \text{ km}\cdot\text{h}^{-1}$ and $30.3 [1.1] \text{ km}\cdot\text{h}^{-1}$. The 95% CI range, between trials, included the null value for difference in TT completion time and was between .88 minutes quicker to 1.57 minutes slower.

****INSERT FIGURE 2 NEAR HERE****

Thermal and f_c Responses

Rectal temperature increased in a linear manner throughout the respective TTs indicating the self-paced exercise produced heat at a rate that was uncompensable (main effect for distance: $F_{(9,63)} = 39.163$, $p = .001$); see table 1. The rate of rise in rectal temperature in the 6 km before spraying was $1.31 [0.70]$ and $1.36 [0.70] \text{ }^\circ\text{C}\cdot\text{hr}^{-1}$ in the CONTROL-SPRAY and MENTHOL SPRAY conditions which were not different ($t = -.227$, $p = .827$). This rate remained similar between condition after spraying at $1.40 [0.60]$ and $1.45 [0.40] \text{ }^\circ\text{C}\cdot\text{hr}^{-1}$ in the respective conditions; and were not different between condition ($t = .461$, $p = .659$). Consequently there was no difference between condition ($F_{(1,7)} = .683$, $p = .436$) or interaction ($F_{(9,63)} = 620$, $p = .776$) for T_{rec} response. Terminal rectal temperature was $38.17 [0.40] \text{ }^\circ\text{C}$ and $38.25 [0.34] \text{ }^\circ\text{C}$ in the CONTROL-SPRAY and MENTHOL-SPRAY conditions respectively.

The mean T_{skin} response was significantly lower after spraying (significant main effect for distance: $F_{(9,63)} = 28.156$, $p = .001$) but these differences only neared an overall condition effect ($F_{(1,7)} = 4.822$, $p = .064$) toward being lower in the MENTHOL-SPRAY condition. However, an interaction effect was evident ($F_{(1,7)} = 3.582$, $p = .001$). Post-hoc analysis showed that the tendency for T_{skin} to be marginally lower in the MENTHOL-SPRAY condition

(-0.36 [0.30] °C) at the 8 (p = .014) and 10 km (p = .013) (i.e. before spraying); evidently this did not produce any difference in thermal perception or T_{rec} before spraying (see figure 1). Consequently, the data were normalised to the T_{skin} before spray application (i.e. at 10 km) to discern if a greater drop in T_{skin} was seen in either condition. This analysis revealed no difference in the magnitude of drop between condition which was -1.25 [0.40] °C and -1.36 [0.36] °C in the CONTROL-SPRAY and MENTHOL-SPRAY conditions respectively at 12 km (see figure 3); no main effect for condition: $F_{(1,7)} = .873$, p = .381 or interaction; $F_{(3,21)} = .121$, p = .947).

****INSERT FIGURE 3 NEAR HERE****

The consequent effects of the T_{rec} and T_{skin} data were very similar estimates of mean body temperature data in each condition and no main effects for condition ($F_{(1,7)} = 1.199$, p = .310) or interaction ($F_{(9,63)} = 1.500$, p = .168) (see table 1).

****INSERT TABLE 1 NEAR HERE****

One f_c data file was corrupted and consequently the data from this participant was removed from the data set (f_c data $n = 7$). f_c data were similar in the first 10 km of the TT in each condition (see Table 1) and showed no evidence of changing as a consequence of spraying in either condition (no main effect for condition: $F_{(1,6)} = .006$, p = .966 or interaction effect: $F_{(7,42)} = .2.491$, p = .140).

Spray Volume and Temperature, Sweat Production and Fluid Consumed

The temperature of the water bath, and consequently the sprays, was measured immediately prior to spray application and were 33.70°C [0.9] °C and 33.40°C [0.1] °C in the CONTROL-SPRAY and MENTHOL-SPRAY conditions and were not different (t = 1.068, p = .321). The volume of spray applied to the t-shirt of the participant was 99.5 [3.3] mL and 98.4 [2.1] mL in the CONTROL-SPRAY and MENTHOL-SPRAY conditions and were not different between conditions (t = .847, p = .425). The volume of fluid consumed by each participant

was consistent between trials and averaged 380 [190] mL and 390 [240] mL in the CONTROL-SPRAY and MENTHOL-SPRAY conditions respectively ($t = -.185$, $p = .858$). These data were combined with naked body mass measurements producing an estimated sweat production of 830 [320] mL and 750 [140] mL in the CONTROL-SPRAY and MENTHOL-SPRAY conditions respectively ($t = .585$, $p = .577$).

Discussion

This study sought to examine whether the application of 0.20 % L-Menthol improved thermal perception and consequently altered self-selected power output during an ecologically valid exercise task; a 16.1 km TT cycle in hot conditions (33.5°C). In advancing previous experiments we applied the L-Menthol towards the end of a self-paced exercise bout, when we expected that participants would be thermally uncomfortable and hyperthermic; our data prior to spray application support this suggestion although only to a modest extent. We also sought to examine whether L-Menthol altered the rate of deep body temperature rise after its application potentially culminating in a greater risk of heat illness. Our data partially support the first experimental hypothesis (H_1) given that the L-MENTHOL spray significantly improved thermal perception by making participants feel cooler (see figure 1A) and more comfortable in the contrast to the CONTROL-SPRAY (see figure 1B). Yet this did not facilitate improved TT performance by enabling participants to sustain a higher power output at a time when the drive to lower exercise intensity (i.e. fatigue) was likely to be increasing. The thermal consequence of the application of both sprays was a transiently lower exercising skin temperature but, when the data were normalised to the pre-spray skin temperature, there was no evidence of a greater drop in skin temperature (see figure 3) which may indicate vasoconstriction when L-MENTHOL was present. Consequently our deep body data temperature suggest that there would be no increased risk of heat illness when L-MENTHOL was applied in the conditions of the present tests; H_2 is therefore rejected. These pacing, performance and thermal perception data are in accordance with our previous investigations which have examined L-MENTHOL application before self-paced

exercise (Barwood et al. 2011 & 2014) but are discrepant, from the point of view of the deep body temperature response, with studies that have investigated L-MENTHOL application during fixed intensity exercise (Gillis et al. 2010). Collectively it seems that the performance enhancing effect of L-MENTHOL spray is not supported.

A novel addition to the literature from the present study is evidence that alleviating thermal discomfort by L-MENTHOL application towards the end of a self-paced exercise bout in the heat also reduces the RPE if only to a small extent. That is, RPE was reduced by approximately one category on the RPE scale (~7%; see figure 1C). This is interesting because RPE is thought to be a primary mediator of self-selected exercise pace (de Koning et al. 2011) and, theoretically, lowering RPE should culminate in a higher self-selected power output (de Koning et al. 2011). Yet this did not result in the present study which, suggests that either changes in RPE of a greater magnitude than seen here are required to induce a change in power output and therefore performance in this population of subjects, or that RPE is not primary driver of exercise in this instance. It is evident that through a mechanism of lowering RPE, L-Menthol could enhance exercise performance in the heat but further studies are required to support this suggestion. We can only speculate that L-MENTHOL enabled a partial dissociation of the thermal cues that contribute to the raised RPE during exercise in the heat.

Our data are discrepant with those who suggest thermal discomfort to be a primary driver of exercise behaviour in hot conditions (Schlader et al, 2011; Marcora et al. 2010). We do not contest this idea but do contend that thermal and perceptual extremes of hyperthermia may need to be achieved before thermal perception becomes sufficiently salient to alter behaviour, and before such time a complex interaction of other drivers of pacing probably prevail (Roelands et al. 2013). In the present study, and in our previous work, relatively modest degrees of discomfort and raised body temperature were achieved (Barwood et al. 2014) following which no change in performance was evident (Barwood et al. 2011 & 2014). We suggest that these thermal and perceptual disturbances were tolerable for the short

period required to complete the exercise task which was achieved before catastrophic homeostatic disturbance was experienced. It may also be that, if L-MENTHOL, improves exercise tolerance rather than performance time, longer exercise bouts in hot conditions could be completed, rather than faster performance, a suggestion that is in keeping with the data of Schlader and colleagues (2011).

Our skin temperature data also support the idea that a relatively modest disturbance in thermal status was achieved (T_{skin} range 33-35°C; see Table 1) in contrast to other studies that have induced higher skin temperatures whilst applying L-MENTHOL (36-37°C; Schlader et al. 2011). Indeed, Nybo et al (2014) suggest that the characteristics of the exercise task and extent of the environmental heat dictate the increase in T_{skin} that is seen. This drives the cardiovascular demand of the exercise bout thereby determining the physiological strain that is induced and the extent of the competing demands between metabolism and thermoregulation for blood flow. Nybo and colleagues (2014) considered a T_{skin} of 33-35°C to be warm and consequently may allow for thermoregulatory and metabolic compensation to be achieved by an increase in cardiac output. At skin temperatures above 35°C there may be little opportunity for compensation and consequently exercise performance in the heat may be limited from a cardiovascular perspective (Cheuvront et al. 2010). It is worthy of note that we have achieved what would be considered 'hot' skin temperatures in previous studies (Barwood et al. 2011 & 2014) albeit when applying L-MENTHOL at the start of exercise yet no performance effect was observed. It remains possible that, in order to discern any beneficial performance effect of L-MENTHOL application, an experiment is required that results in T_{skin} that is considered to be 'hot' rather than 'warm' with L-MENTHOL is applied toward the end of an exercise bout where high levels of environmental, thermoregulatory and cardiovascular strain are present; this represents a highly specific set of circumstances. From the perspective of exercise in hot conditions in light athletic clothing, the extremes of T_{skin} are only likely to be achieved at very high intensities of exercise and/or at extremely high ambient temperatures perhaps in the presence of an additional solar load.

The present study is not without limitation. We tested recreationally active rather than trained participants in whom other factors, such as heat tolerance (Ely et al. 2009), might be limiting in this exercise paradigm. It would clearly be of interest to examine the effect of L-MENTHOL application sprayed towards the end of an exercise bout in the heat in a trained population who are better able to tolerate hyperthermia and perform consistently in hot conditions (Tikusis et al. 2002; Ely et al. 2009). In defence of this, we have seen in the present and previous studies (Barwood et al. 2014) highly consistent pacing templates (see figure 2) and performance times in this type of recreationally active participant group. Hence we feel our conclusions are appropriate. We also suggest that, due to evidence of increasing participation rates in athletic events (Lee et al. 2010), the population studied here is likely to represent consumers of products that purport to enhance exercise performance in the heat such as those that include L-MENTHOL. Collectively, our series of studies demonstrate, there has been no trend towards enhanced performance with L-MENTHOL use despite improved perception of thermal sensation, comfort and perceived exertion (Barwood et al. 2011 & 2014); the latter only evident in the present study. It is also possible that we did not test enough participants to see a difference in terminal T_{rec} that we may expect between our two spray conditions. We estimate that we would be required to test a further 160 participants to meet accepted statistical power levels using the measured difference we report here between spray trials (0.08°C , SD $[0.37]^{\circ}\text{C}$) in terminal T_{rec} (DSS Research Power Calculator; 80% statistical power & alpha level of 0.05). This was not feasible in the present study. It would also have been valuable to directly measure blood flow rather than a surrogate such as T_{skin} . We are clearly assuming that any vasoconstriction induced by L-MENTHOL application would result in lower surface skin temperature and consequently result in a higher deep body temperature as has been shown at higher concentrations of L-MENTHOL (4.6 % L-MENTHOL sediment; Kounalakis et al. 2010; 0.80 % L-MENTHOL spray; Lee et al., 2012). In the present study, it is evident that the L-MENTHOL effectively uncoupled the relationship with T_{skin} and thermal perception shown by the lower thermal perceptions after spraying with a similar magnitude of drop in T_{skin} between sprays.

In conclusion, L-MENTHOL application to the t-shirt covering the torso in 100 mL of solution makes participants feel cooler and consequently more comfortable. This likely contributed to the small reduction in exercise RPE that was observed. Yet, this did not result in enhanced self-paced exercise performance of an ecologically valid task. These studies were conducted in relatively untrained participants so the ergogenic potential of L-MENTHOL should also be addressed in trained athletes. We also examined the possibility that L-MENTHOL application could have increased the risk of heat illness by impairing heat loss responses thereby increasing the rate of deep body temperature rise and absolute temperature that was reached. Our data show no support for this possibility. The improvement in the perceptual response to exercise, coupled with the lack of effect on thermoregulatory responses (and therefore no increase in the risk of heat illness) indicates L-MENTHOL application could be an effective strategy to improve exercise adherence in hot environments rather than inducing better performance.

Perspective

Mass participation endurance events often take place in hot conditions. There are a variety of ergogenic aids that may enhance (or impair) exercise performance in such conditions and these athletes, irrespective of competitive level, must decide based on the available evidence, which of these products to invest in to facilitate performance. L-Menthol is one such product. We have consistently shown that L-Menthol application either before or toward the end of exercise induces cool sensations and consequently alleviates thermal discomfort; we consider this to be a perceptual benefit. When applied toward the end of exercise, as in the present study, perceived exertion is also lowered. Despite these perceptual benefits performance remains unchanged.

It was also possible that L-Menthol application could trigger heat gain responses resulting in increased risk of heat illness. We have found no evidence of this during self-paced exercise suggesting L-Menthol is relatively safe to use in conditions and concentrations similar to the present and previous studies. Athletes must decide whether the perceptual benefit is

worthwhile in the absence of any evidence of performance enhancement. It remains possible that L-Menthol spray would be effective in improving heat tolerance and performance in extreme thermal states or in hotter environments.

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Tables

Table 1: Mean [SD] T_{rec} , T_{skin} , T_{body} (all $n = 8$) and f_c ($n = 7$) response during the 16.1 km cycling TTs in the CONTROL-SPRAY and MENTHOL-SPRAY conditions; * denotes significant difference between conditions.

	0 km	2 km	4 km	6 km	8 km	10 km	12 km	14 km	16 km
CONTROL- SPRAY T_{rec} (°C)	37.5 [0.3]	37.5 [0.3]	37.6 [0.3]	37.7 [0.3]	37.8 [0.3]	37.9 [0.3]	38.0 [0.3]	38.1 [0.4]	38.2 [0.4]
MENTHOL- SPRAY T_{rec} (°C)	37.5 [0.2]	37.5 [0.2]	37.6 [0.2]	37.7 [0.2]	37.8 [0.2]	37.9 [0.2]	38.0 [0.3]	38.2 [0.3]	38.3 [0.3]
CONTROL- SPRAY T_{skin} (°C)	33.4 [0.5]	33.6 [0.4]	34.0 [0.4]	34.2 [0.4]	34.4 [0.4]*	34.3 [0.4]*	33.1 [0.5]*	33.3 [0.6]*	33.6 [0.5]*
MENTHOL- SPRAY T_{skin} (°C)	33.6 [0.7]	33.6 [0.6]	33.8 [0.5]	34.0 [0.5]	34.0 [0.4]	34.0 [0.5]	32.7 [0.5]	32.9 [0.4]	33.1 [0.4]
CONTROL- SPRAY T_{body} (°C)	36.7 [0.4]	36.9 [0.3]	37.0 [0.3]	37.2 [0.3]	37.3 [0.3]	37.4 [0.3]	37.0 [0.3]	37.1 [0.4]	37.3 [0.4]
MENTHOL- SPRAY T_{body} (°C)	36.9 [0.3]	36.9 [0.2]	37.0 [0.2]	37.1 [0.1]	37.2 [0.2]	37.3 [0.2]	36.9 [0.2]	37.0 [0.2]	37.2 [0.2]
CONTROL- SPRAY f_c (b.min ⁻¹)	-	143 [12]	162 [14]	168 [14]	171 [14]	172 [14]	169 [16]	172 [16]	177 [16]
MENTHOL- SPRAY f_c (b.min ⁻¹)	-	148 [26]	157 [21]	168 [14]	173 [12]	175 [11]	175 [9]	178 [9]	181 [6]

Figure Legends

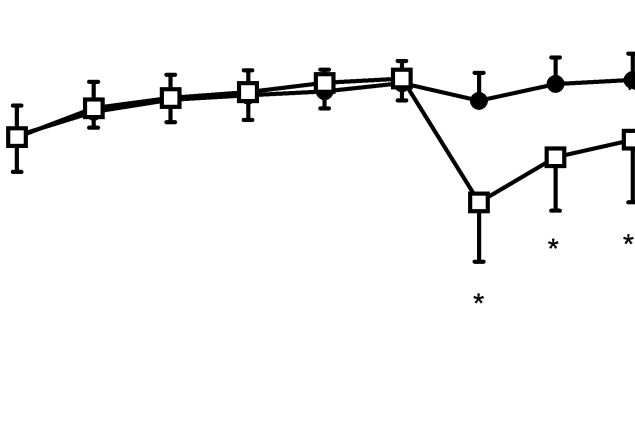
Figure 1. Perceptual responses during the 16.1 km cycling TTs in CONTROL-SPRAY and MENTHOL-SPRAY conditions. Panel A, thermal sensation (cm), B, thermal comfort (cm) and C, rating of perceived exertion (arbitrary units). Values are mean [SD], * denotes significant difference between conditions ($n = 8$).

Figure 2. Power output (Watts) during the 16.1 km cycling TTs in the CONTROL-SPRAY and MENTHOL-SPRAY conditions. Values are mean [SD]; * denotes significant difference between conditions ($n = 8$).

Figure 3. ΔT_{skin} ($^{\circ}\text{C}$) response normalised against T_{skin} at 10 km in final 6.1 km of the 16.1 km cycling TTs in the CONTROL-SPRAY and MENTHOL-SPRAY conditions ($n = 8$). Values are mean [SD * denotes significant difference between conditions ($n = 8$).

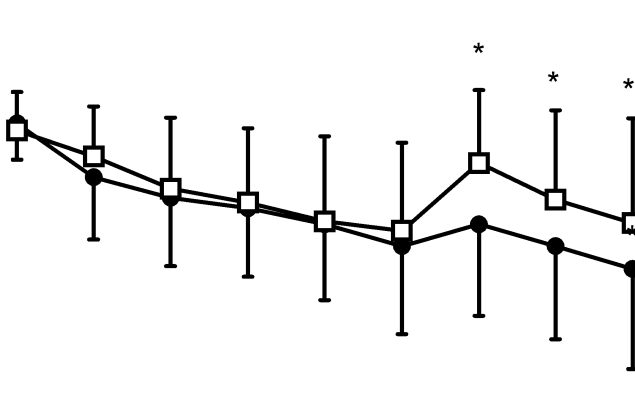
A

Very hot
Hot
Warm
Slightly warm
Neutral
Slightly cool
Cool
Cold
Very cold



B

Very comfortable
Comfortable
Just comfortable
Just uncomfortable
Uncomfortable
Very uncomfortable



C

Very, very hard
Very hard
Hard
Somewhat hard
Fairly light
Very light
Very, very light

