

# Northumbria Research Link

Citation: Barwood, Martin J., Kupusarevic, Joe and Goodall, Stuart (2019) Enhancement of Exercise Capacity in the Heat With Repeated Menthol-Spray Application. *International Journal of Sports Physiology and Performance*, 14 (5). pp. 644-649. ISSN 1555-0265

Published by: UNSPECIFIED

URL:

This version was downloaded from Northumbria Research Link: <http://northumbria-test.eprints-hosting.org/id/eprint/51285/>

Northumbria University has developed Northumbria Research Link (NRL) to enable users to access the University's research output. Copyright © and moral rights for items on NRL are retained by the individual author(s) and/or other copyright owners. Single copies of full items can be reproduced, displayed or performed, and given to third parties in any format or medium for personal research or study, educational, or not-for-profit purposes without prior permission or charge, provided the authors, title and full bibliographic details are given, as well as a hyperlink and/or URL to the original metadata page. The content must not be changed in any way. Full items must not be sold commercially in any format or medium without formal permission of the copyright holder. The full policy is available online: <http://nrl.northumbria.ac.uk/policies.html>

This document may differ from the final, published version of the research and has been made available online in accordance with publisher policies. To read and/or cite from the published version of the research, please visit the publisher's website (a subscription may be required.)



UniversityLibrary



**Northumbria**  
**University**  
NEWCASTLE

1 Repeated Menthol spray application enhances exercise capacity in the heat

2  
3 Martin J Barwood<sup>1</sup>, Joe Kupusarevic<sup>2</sup>, Stuart Goodall<sup>3</sup>

4  
5 <sup>1</sup>Department of Sport, Health and Nutrition, Leeds Trinity University, Horsforth,  
6 Leeds, LS18 5HD, U.K

7  
8 <sup>2</sup>Institute of Cellular Medicine, Newcastle University, Newcastle Upon Tyne, NE1  
9 7RU, U.K

10  
11 <sup>3</sup>Department of Sport, Exercise and Rehabilitation, Northumbria University, Newcastle  
12 Upon Tyne, NE1 8ST, U.K

13  
14  
15 Submission type: Original Investigation

16 Running head: Thermal perception and exercise performance

17  
18 Abstract Word Count: 249

19 Manuscript Word Count: 3500

20 Number of Tables: 0

21 Number of Figures: 2

22  
23  
24  
25 Corresponding Author: Dr Martin Barwood, Dept. of Sport, Health and Nutrition,  
26 Leeds Trinity University, Brownberrie Lane, Horsforth, West Yorkshire, LS18 5HD,  
27 U.K. Tel: +44 (0) 113 287 3100. Fax: +44 (0) 113 287 3101. Email:  
28 [M.Barwood@leedstrinity.ac.uk](mailto:M.Barwood@leedstrinity.ac.uk)

29

30 **Abstract**

31

32 **Purpose.** Exercise performance is impaired in the heat and a contributing factor to this  
33 decrement is thermal discomfort. Menthol-spraying of skin is one means of alleviating  
34 thermal discomfort but has yet to be shown to be ergogenic using single spray  
35 applications. We examined whether repeated menthol-spraying could relieve thermal  
36 discomfort, reduce perception of exertion and improve exercise performance in hot  
37 (35°C), dry (22% RH) conditions; we hypothesised it would. **Method.** Eight trained  
38 cyclists completed two separate conditions of fixed intensity (FI) cycling (50% P<sub>Max</sub>)  
39 for 45-minutes before a test to exhaustion (TTE; 70% P<sub>Max</sub>) with 100 mL of menthol-  
40 spray (0.20% menthol) or control-spray applied to the torso after 20 and 40-minutes.  
41 Perceptual (thermal sensation (TS), thermal comfort (TC), RPE) performance (TTE  
42 duration), thermal variables (skin temperature (T<sub>skin</sub>), rectal temperature (T<sub>rec</sub>), cardiac  
43 frequency (*fc*)) and sweating were measured. Data were compared using ANOVA to  
44 0.05 alpha level. **Results.** Menthol-spray improved TS (*'cold'* sensation *cf* *'warm/hot'*  
45 after first spraying; *p*=.008) but only descriptively altered TC (*'comfortable'* *cf*  
46 *'uncomfortable'*; *p*=.173). Sweat production (994 (380) mL *cf* 1180 (380); *p*=.020) mL  
47 and rate (827 (327)mL·hr<sup>-1</sup> *cf* 941 (319)mL·hr<sup>-1</sup>; *p*=.048) lowered. TTE performance  
48 improved (4.6 (1.74) *cf* 2.4 (1.55) minutes (*p*=.004). Menthol-spray effects diminished  
49 despite repeated applications indicating increased contribution of visceral  
50 thermoreceptors to thermal perception. **Conclusion.** Repeated menthol-spray improves  
51 exercise capacity but alters thermoregulation potentially conflicting behavioural and  
52 thermoregulatory drivers; care should be taken with its use. Carrying and deploying  
53 menthol-spray would impose a logistical burden which needs consideration against  
54 performance benefit.

55

56 **Keywords.** TRPM8 receptors, thermoregulation, sweating, thermal perception.

57

58

59 **Introduction**

60

61 Exercise performance is impaired in hot conditions with fatigue occurring prematurely  
62 compared to cool environments<sup>1</sup>. The aetiology of this fatigue is complex and  
63 multifaceted but is in part attributable to increased thermal sensations (i.e. feeling hot)  
64 and thermal discomfort<sup>2</sup>. Accordingly, any intervention that offsets these disturbances  
65 in thermal perception may prove to be ergogenic and influence exercise behaviour<sup>3</sup>.  
66 One such intervention with the potential to do so is the topical application of menthol  
67 to the skin. This has been found to change the action potential of the Transient Receptor  
68 Potential Melastatin 8 (TRPM8) subfamily of thermoreceptors thereby inducing cool  
69 sensations<sup>4,5</sup>. Although, menthol is also known to activate TRP vanilloid (TRPV) and  
70 ankyrin (TRPA) receptors<sup>6</sup> above temperatures of 37 °C thereby inducing warm  
71 sensations<sup>7</sup>. Accordingly in exercise and environmental scenarios where skin  
72 temperatures do not exceed 37 °C (i.e. the majority of scenarios) the chemical  
73 stimulation of the skin by menthol appears to be a viable means of improving thermal  
74 perception and potentially exercise performance.

75

76 Only one study to date has revealed an ergogenic benefit following the topical  
77 application of an 8% menthol gel applied to the face during self-paced exercise  
78 performed at a fixed perception of exertion<sup>2</sup>. Menthol application induced an  
79 approximate 18% increase in total work during the study where thermal stress was  
80 applied through a water-perfused suit<sup>2</sup>. Thermal perception was shown to be a relatively  
81 independent behavioural regulatory influence on exercise termination as shorter  
82 exercise duration was observed with the induction of hot sensations by capsaicin  
83 application to the skin<sup>2</sup>. However, in studies performed using ecologically valid  
84 laboratory protocols<sup>3,8,9</sup> an ergogenic effect has proved illusive leading to suggestions  
85 that menthol-spraying may only improve thermal perception but not performance<sup>10</sup>.  
86 Menthol applied to the skin at concentrations (0.05 to 0.20 % L-Menthol in solution),  
87 similar to that of commercially available products (Physicool™, London, U.K), has  
88 been reliably shown to induce improvements in thermal sensation and comfort, during  
89 fixed intensity<sup>11</sup> and self-paced exercise<sup>3,8,9</sup> in the heat. However, it has also been  
90 shown to induce heat gain responses (i.e. vasoconstriction<sup>11</sup>) and alter sweating  
91 responses<sup>12</sup>; in the latter case at higher concentrations (i.e. 4.6%<sup>12</sup>). Therefore, it is also  
92 plausible that menthol application could increase the risk of heat-illness and place  
93 behavioural and thermoregulatory drivers in conflict.

94

95 Nevertheless, there are iterations on the timing of menthol application that have not  
96 been explored experimentally which may mean concluding a lack of ergogenic effect  
97 is premature. To date, we have explored whether relieving thermal discomfort and  
98 improving thermal sensation is performance enhancing prior to and during the early  
99 minutes of a 40 km cycling time trial; it was not<sup>8</sup>. We have examined whether inducing  
100 hot and uncomfortable sensations using a heat pre-load followed by menthol  
101 application would result in improved performance of a shorter duration exercise of 5  
102 km running but it did not<sup>9</sup>. Most recently we examined whether applying menthol  
103 towards the end of an exercise task (i.e. at 10 km of a 16.1 km cycling time trial; TT)  
104 would result in benefits to TT completion time<sup>3</sup>. Once again we saw no improvement  
105 although menthol-spray application did result in lowered RPE in addition to benefits to  
106 thermal perception. Each of these studies, and others where perceptual manipulation  
107 was the primary goal<sup>11</sup> involved *single* applications of menthol-spray. It has yet to be  
108 investigated whether *repeated* menthol application can act as an ergogenic aid.

109 Theoretically, in prior studies the acute bouts of thermal discomfort relief through  
110 menthol-spray application may have been insufficient to perturb the behavioural  
111 thermoregulatory drivers towards altering exercise performance. Whereas *repeated*  
112 application may provide a greater driver to change this. Moreover, the nature of the  
113 exercise task may also be important. Menthol is evidently more likely to influence an  
114 exercise task where tolerance is the critical factor<sup>10</sup> (e.g. test to exhaustion; TTE) rather  
115 than the spontaneous variation in power output (e.g. TT) which have consistently failed  
116 to be responsive to menthol in three of our previous studies<sup>3,8,9</sup>. Accordingly, the  
117 present study sought to examine this possibility.

118

119 We hypothesised that menthol application, applied every 20-minutes during exercise in  
120 the heat<sup>11</sup>, would enhance exercise performance in a subsequent TTE where heat  
121 tolerance is the main limiting factor to performance (H<sub>1</sub>). We also hypothesised that  
122 menthol-spray application would enhance thermal perception by inducing cool thermal  
123 sensations and relieving thermal discomfort which may result in reduced perception of  
124 exertion in contrast to a control-spray condition (H<sub>2</sub>).

125

## 126 **Method**

127

### 128 ***Experimental Design***

129 The local ethics committee approved the study which used a within participant,  
130 repeated measures design in which participants completed three exercise conditions.  
131 The first condition took place in a temperate environment and was to establish their  
132 maximal power output (P<sub>Max</sub>) for use during the subsequent two conditions which took  
133 place in a hot environment. Conditions two and three were counter-balanced where the  
134 participants' t-shirt was repeatedly sprayed (i.e. every 20-minutes) with a menthol-  
135 spray or a control-spray. Tests took place at the same time of day ( $\pm$  1 hour) with a  
136 minimum of 48 hours between tests.

137

### 138 ***Participants***

139 Eight trained cyclists (mean  $\pm$  SD: age  $22 \pm 2$  yrs; height  $1.84 \pm 0.1$  m; body surface  
140 area<sup>13</sup>  $2.05 \pm 0.1$  m<sup>2</sup> P<sub>Max</sub>  $362.5 \pm 35.4$  W) volunteered and provided written informed  
141 consent. Participants were considered trained if they achieved a minimum P<sub>Max</sub> of  $\geq 350$   
142 watts<sup>14</sup>. Participants abstained from alcohol, caffeine consumption and strenuous  
143 exercise 24 hours prior to each test and were non-smokers.

144

### 145 ***Procedures***

146 *Condition One - P<sub>Max</sub> Test:* Participants arrived at the laboratory wearing cycle clothing.  
147 They were instrumented with a heart rate monitor (FT1, Polar Electro Oy, Kempele,  
148 Finland) and entered the environmental chamber held at a temperature of 16°C.  
149 Participants were made comfortable on the cycle ergometer (Velotron, Racermate,  
150 Seattle, USA); bike positioning was replicated for subsequent visits. Participants  
151 completed a standardised 5-minute warm up at 150 W and a cadence of 70 rev·min<sup>-1</sup>  
152 followed by stretching. They remounted the ergometer and recommenced cycling at the  
153 same power output and cadence as the warm-up. The required power output was  
154 increased by 50 W every 2-minutes until volitional exhaustion or when the prescribed  
155 cadence could not be maintained for 15-seconds and having achieved a heart rate within  
156 10 b.p.m<sup>-1</sup> of age predicted maximum. Participants were instructed prior that they  
157 should make a maximal effort during the test.

158 *Conditions Two and Three - Repeated Spray Applications:* Participants arrived in a  
159 hydrated state; i.e. having consumed 500 mL of water the preceding night and 500 mL  
160 in the two hours prior to arrival at the laboratory. Participants were allowed to drink  
161 tepid tap water during the trials. Participants first voided and naked body mass was  
162 measured in private (Seca, Model 705 2321009, Vogel & Halke, Hamburg, Germany).  
163 They then donned their cycling shorts and were instrumented with a calibrated,  
164 insulated rectal thermistor (Grant Instruments Ltd, Cambridge [Shepreth], U.K)  
165 inserted (in private) 12-15 cm beyond the anal sphincter. They were also instrumented  
166 with skin thermistors (Grant Instruments Ltd, Cambridge [Shepreth], U.K) placed at  
167 eight different body sites<sup>15</sup> on the left side of the body secured by breathable tape  
168 (Transpore<sup>TM</sup>,1527-1, 3M Health Care, MN, USA). A heart rate monitor was also  
169 worn to measure cardiac frequency ( $f_c$ ). Rectal temperature ( $T_{rec}$ ) and skin temperature  
170 ( $T_{skin}$ ) were logged automatically every 5-seconds using a remote data logger (Squirrel  
171 2020 series, Grant Instruments Ltd, Cambridge [Shepreth], U.K). Following  
172 instrumentation participants completed dressing by wearing socks, shoes and a close-  
173 fitting long sleeve t-shirt (100% polyester; Campri Sports Baselayer, Sportsdirect,  
174 Shirebrook, U.K). Identical clothing was worn in each condition that involved repeated  
175 spraying.

176  
177 Participants then entered an environmental chamber set to 35°C and 20% relative  
178 humidity (RH). Environmental conditions were measured by a wet-bulb, globe,  
179 temperature (WBGT) station (1000 series, Squirrel Data Logger, Grant Instruments  
180 Ltd, Cambridge [Shepreth], U.K). One minute prior to the start of exercise, all data  
181 logging systems were activated and synchronised. Prior to the commencement in  
182 exercise participants provided a resting capillary sample of blood for measurement of  
183 blood lactate concentration ( $B_{lac}$ ). Participants also reported their resting thermal  
184 comfort ( $TC^{16}$ ) and thermal sensation ( $TS^{16}$ ). Participants then mounted the cycle  
185 ergometer and completed the same standardised warm up as prior to the  $P_{Max}$ , and then  
186 commenced fixed intensity (FI) cycling at 50%  $P_{Max}$  for 45-minutes. Participants  
187 cycled in front of a fan positioned 80 cm from the velotron (Wahl, Model ZX220, Wahl,  
188 Sterling, IL, USA) and pointed at the participants' torso. The wind speed produced by  
189 the fan was verified at a fixed position by an anemometer (LM-8000 Anemometer,  
190 Digital Instruments, New York, USA; this approximated between 1.6 and 2.1  $m \cdot s^{-1}$ ).

191  
192 Perceptual responses including RPE<sup>17</sup>, TC and TS were obtained initially every 10-  
193 minutes of the FI period, until (i.e before) the first spray application at 20-minutes.  
194 They were recorded every 5-minutes thereafter; RPE was not collected at 30-minutes.  
195 After 20 and 40-minutes of exercise participants' jerseys were sprayed evenly with 100  
196 mL of either the control-spray or the menthol-spray which was heated in a water bath  
197 to match environmental temperature<sup>3</sup>. Spray volume was measured on each occasion  
198 using calibrated, digital, weighing scales (Sartorius Mechatronics UK Ltd, TE6100,  
199 Surrey, U.K; 1 g resolution). Intervals between sprays were 20-minutes on the basis  
200 that the menthol-spray perceptual response has been shown to decay thereafter<sup>11</sup>.  
201 Sprays were produced by an independent chemical consultant (Chemical Associates,  
202 Rosemead, Frodsham, United Kingdom). The control-spray contained 3% surfactants  
203 mixed in water, while the menthol-spray contained a concentration of 0.20 wt/wt L-  
204 menthol in 3% surfactants plus water.

205  
206 Upon completion of the FI period participants provided another capillary blood sample  
207 and immediately commenced a test to exhaustion (TTE) at 70 %  $P_{Max}$ . Participants

208 received no feedback of exercise time elapsed or encouragement during the TTE. Upon  
209 TTE cessation (i.e. volitional exhaustion) the participant exited the chamber and were  
210 weighed naked and, in conjunction with measured fluid intake, sweat production and  
211 sweat rate were calculated. Performance times were not revealed until the post-  
212 experiment debrief.

213

### 214 ***Statistical Analysis***

215 Mean (SD) were calculated for perceptual (TS, TC, RPE), performance, ( $B_{lac}$ , TTE  
216 duration), thermal ( $T_{skin}$ ,  $T_{rec}$  and  $f_c$ ) spray variables (temperature and volume),  
217 environmental conditions and sweat production including rate. The normality of  
218 distribution was verified using a Kolmogorov-Smirnov test. Data were compared  
219 using a repeated measures analysis of variance (ANOVA) at rest and fixed points  
220 during the FI period including TTE end point for the two hot trials (9 x 2 ANOVA) for  
221 perceptual (no RPE measure at rest and 30-minute point) and thermal variables.  
222 Sphericity was checked using Mauchly's test and, where necessary, a Greenhouse-  
223 Geisser adjustment was applied. The direction of statistically significant effects were  
224 determined using Fisher's (LSD) *post-hoc* pair-wise comparisons. Partial eta squared  
225 ( $\eta^2$ ) are reported as estimates of effect size. Environmental conditions, spray  
226 temperature, volume, TTE duration, fluid consumed, sweat data and terminal  $B_{lac}$  were  
227 compared using paired samples t-test. The 95% confidence interval (CI) was calculated  
228 for the TTE data. Data are otherwise presented as mean (SD). An alpha level of 0.05  
229 was used for all statistical tests which were conducted using SPSS (SPSS v 21, IBM,  
230 Chicago, Illinois, USA) and Prism (Graphpad, Prism v 6, San Diego, USA).

231

## 232 **Results**

233

### 234 ***Environmental Conditions***

235 Ambient temperature averaged 35.0 (1.3) °C and 34.6 (1.2) °C in the control-spray and  
236 menthol-spray conditions respectively and did not differ ( $t = .846$ ,  $p = .213$ ). RH  
237 averaged 21.8 (0.90) % and 22.2 (1.0) % and did not differ ( $t = -1.06$ ,  $p = .162$ ).

238

### 239 ***Spray Volume and Temperature***

240 Volume of spray applied was 200 (3) mL in the control-spray and 200 (2) mL in the  
241 menthol-spray conditions which were similar ( $t = 0.110$ ,  $p = 0.460$ ). The temperature  
242 of the control-spray averaged 37.4 (1.2) °C and was 38.3 (1.6) °C in the menthol-spray  
243 condition and were not different ( $t = 1.766$ ,  $p = .097$ ).

244

### 245 ***TTE Performance***

246 TTE was 2.4 (1.55) minutes and 4.6 (1.74) minutes in the control-spray and menthol-  
247 spray conditions respectively and was significantly greater after menthol-spraying  
248 application ( $t = -3.63$ ,  $p = 0.004$ ; 95% CI 0.53 to 3.82 minutes).

249

### 250 ***Perceptual Responses***

251 Participants' TS responses were similar in each condition before the first spray (i.e. at  
252 20 minutes) and corresponded to the worded descriptor 'hot'. At 25-minutes, 5-minutes  
253 after spraying, TS was significantly lower (main effect for condition:  $F_{(1, 7)} = 13.139$ ,  $p$   
254  $= 0.008$ ,  $\eta^2 = .652$  & interaction effect:  $F_{(8, 56)} = 12.843$ ,  $p = 0.001$ ,  $\eta^2 = .441$ ) in the  
255 menthol-spray condition (11.0 (2.4) cm) compared to the control-spray (15.7 (1.6) cm;  
256  $p = 0.02$ ). These ratings corresponded to the worded descriptors 'warm' to 'hot' in the  
257 control-spray and 'cold' in the menthol-spray condition. The differences due to



258 menthol-spraying remained until 40-minutes where TS was not different ( $p = .255$ ).  
259 Following the second administration of menthol-spray TS once again declined (i.e.  
260 participants felt cooler) significantly ( $p = .035$ ); see figure 1A.

261  
262  
263  
264  
265

\*\*\*Insert figure 1 near here\*\*\*

266 The differences in TS only resulted in numerical changes in TC after spray application  
267 (no condition effect:  $F_{(1, 7)} = 2.297$ ,  $p = .173$ ,  $\eta^2 = .247$ ; no interaction effect:  $F_{(8, 56)} =$   
268  $4.789$ ,  $p = .270$ ,  $\eta^2 = .155$ ) probably because of larger variation in the TC response  
269 than TS. At 25-minutes, after first spray application, TC averaged 9.0 (3.9) cm and 11.8  
270 (1.6) cm in the control-spray and in the menthol-spray conditions respectively  
271 corresponding to the worded descriptors ‘*uncomfortable*’ and ‘*comfortable*’; see figure  
272 1B.

273  
274  
275  
276  
277

RPE did not differ between conditions (condition effect:  $F_{(1, 7)} = .057$ ,  $p = .819$ ,  $\eta^2 =$   
 $.008$ ) or show any interaction effect ( $F_{(6, 42)} = .782$ ,  $p = .620$ ,  $\eta^2 = .101$ ). RPE was  
always within one RPE rating between condition; see figure 1C.

### 278 ***Thermal Responses (Including $f_c$ )***

279 One  $T_{rec}$  file was corrupted and consequently data from this participant were removed  
280 ( $T_{rec}$  data  $n = 7$ ).  $T_{rec}$  increased steadily throughout FI exercise and the TTE, indicating  
281 that the exercise produced heat at a rate that was uncompensable (main effect for time:  
282  $F_{(7, 42)} = 49.490$ ,  $p = .001$ ,  $\eta^2 = .892$ ); see figure 2A. There was no difference between  
283 condition ( $F_{(1, 6)} = .017$ ,  $p = .899$ ,  $\eta^2 = .003$ ) or interaction effect for  $T_{rec}$  ( $F_{(7, 42)} =$   
284  $2.097$ ,  $p = .182$ ,  $\eta^2 = .259$ ). Terminal rectal temperature was 38.5 (0.26) and 38.4  
285 (0.37) °C in the control-spray and menthol-spray conditions respectively. The  $T_{skin}$   
286 response was similar for the first 20-minutes of FI exercise before spray application.  
287 Despite the changes in TS, there was no evident condition effect for  $T_{skin}$  ( $F_{(1, 7)} = .444$ ,  
288  $p = .527$ ,  $\eta^2 = .105$ ) or any interaction effect ( $F_{(7, 49)} = .575$ ,  $p = .389$ ,  $\eta^2 = .147$ )  
289 although  $T_{skin}$  did change numerically in the same direction as the TS ratings. These  
290 data indicate an uncoupling of the  $T_{skin}$  and thermal perceptual response; see figure 2B.  
291 Following the first menthol-spray application the  $T_{skin}$  response had a tendency to be  
292 numerically lower until the commencement of the TTE; see figure 2B.  $f_c$  was similar  
293 throughout each condition and averaged 171 (14)  $b \cdot min^{-1}$  and 174 (7)  $b \cdot min^{-1}$  in the  
294 control-spray and menthol-spray condition at test cessation. There was no difference  
295 between condition ( $F_{(1, 7)} = .053$ ,  $p = .825$ ,  $\eta^2 = .008$ ) or interaction ( $F_{(5, 35)} = .108$ ,  $p =$   
296  $.990$ ,  $\eta^2 = .015$ ).

297  
298  
299

\*\*\*Insert figure 2 near here\*\*\*

300  
301

### 302 ***Fluid Consumed, Sweat Produced, Blood lactate and Cardiac Frequency***

303 The volume of fluid consumed by each participant was relatively consistent between  
304 conditions and averaged 630 (169) mL and 545 (187) in the control-spray and menthol-  
305 spray conditions ( $t = 1.12$ ,  $p = .149$ ). These data combined with naked body mass  
306 measurements generated an estimated sweat production of 1180 (380) mL and 994  
307 (380) mL in the control-spray and menthol-spray conditions with production being

308 lower after menthol-spray ( $t = 3.002$ ,  $p = .020$ ). Due to the significantly longer exercise  
309 duration in the menthol-spray condition the estimated sweat rate ( $827$  ( $327$ )  $\text{mL}\cdot\text{hr}^{-1}$ )  
310 was reduced ( $t = 2.392$ ,  $p = .048$ ) versus the control-spray condition ( $941$  ( $319$ )  $\text{mL}\cdot\text{hr}^{-1}$ ).  
311

312  
313 Terminal  $B_{\text{lac}}$  at the end of the FI period was  $4.3$  ( $2.1$ )  $\text{mmol/L}$  and  $5.1$  ( $3.1$ )  $\text{mmol/L}$  in  
314 the control-spray and menthol-spray conditions and was not different ( $t = 1.189$ ,  $p =$   
315  $0.273$ ); further  $B_{\text{lac}}$  data not shown.

316

## 317 **Discussion**

318

319 The present study sought to examine whether *repeated* application on menthol-spray to  
320 the torso enhanced exercise performance in trained cyclists in an exercise task which  
321 was limited by tolerance rather than power output. Our data showed an improvement  
322 in TTE performance of  $133$  ( $104$ ) seconds after menthol-spraying in contrast to a  
323 control-spray condition;  $H_1$  is therefore accepted. We also suggested that *repeated*  
324 menthol-spray application would provide a greater benefit to thermal perception  
325 thereby driving behavioural thermoregulation. Our data suggest that only thermal  
326 sensation was significantly improved although thermal comfort did alter subjectively  
327 in the hypothesised direction. The performance change through perceptual mechanisms  
328 did not manifest itself through lowered perceived exertion; we therefore only provide  
329 partial support for  $H_2$ . An additional novel finding was the change observed in sweat  
330 production and sweat rate following repeated menthol-spray application which we have  
331 not seen previously with single application studies using this menthol concentration.

332

333 To our knowledge, this is the first study to investigate the possibility of an ergogenic  
334 effect of repeated menthol application using an ecologically valid protocol and a  
335 menthol concentration similar to those commercially available. The fact that repeated  
336 menthol application is required to produce an ergogenic effect provides a challenge to  
337 performers of sports where a weight bearing component may be limiting to their  
338 performance (e.g. running, tour cycling). A decision to carry and deploy menthol must  
339 be balanced against any performance decrement induced by bearing the additional  
340 weight. Moreover, our evidence that the perturbation in thermal perception was lesser  
341 after the second menthol spray application also suggests that repeated chemical  
342 stimulation of the skin may have limitations especially in a hot environment. Indeed,  
343 we speculate that repeated menthol application is likely to have a lesser effect because  
344 of acute habituation to the sensation<sup>18</sup> or because of an increased contribution of raised  
345 deep body temperature to thermoreception thereby reducing the contribution  $T_{\text{skin}}$   
346 makes to thermal perception<sup>19</sup>. Even in the scenario of hot skin and a normothermic  
347 deep body temperature, menthol may evoke warm sensations if the mean  $T_{\text{skin}}$  is over  
348  $37^\circ\text{C}$  which has been shown in isolated cells to activate warm sensitive thermoreceptors  
349 TRPA and TRPV<sup>6</sup>. In the present study, activation of these thermoreceptors by menthol  
350 may also contribute to the lessened perceptual effect with repeated application.  
351 Consequently, a combination of peripheral and visceral thermoreceptor stimulation  
352 may be a more viable target for performance enhancement rather than visceral or  
353 peripheral alone. There is good evidence that menthol ingestion is performance  
354 enhancing<sup>10</sup> and we show here it is premature to conclude that topical application is  
355 not. It is now also plausible that topical menthol application could be ergogenic in other  
356 activities (e.g. strength and power-based activities) which could be limited by hot

357 environments or the perceptual mechanisms we describe here and elsewhere in relation  
358 to RPE<sup>3</sup>.

359

360 The fact that repeated menthol-spray also altered sweating response by reducing it is  
361 also a novel finding although others have reported delayed sweating and reduced sweat  
362 production occurs after 4.6% menthol sediment application<sup>12</sup>. The extent of the  
363 reduction we see in the present study, albeit using different protocols and menthol  
364 concentrations (i.e. 0.20% *cf* 4.6%), was far lower (i.e. 12% *cf* 63% of sweat response  
365 seen in the control condition) than reported elsewhere<sup>12</sup> indicating a dose response  
366 relationship for menthol application to the skin. Others have also reported that menthol  
367 application activates different heat gain responses including vasoconstriction with  
368 resultant increases in rectal temperature<sup>11,12</sup>. Although we did not see the latter, we also  
369 saw evidence that  $T_{\text{skin}}$  was lowered after menthol-spray application (see figure 2B)  
370 indicating possible vasoconstriction. Any change in  $T_{\text{skin}}$  was also less substantial on  
371 secondary application supporting the idea that visceral thermoreceptors are applying a  
372 greater predominance of thermoregulatory input as deep body temperature increases<sup>20</sup>.  
373 Collectively across our study and those of others, we must be cautious when titrating  
374 the concentration and frequency of menthol application during exercise to avoid  
375 inducing heat gain responses which may increase heat illness risk, especially during  
376 high intensity efforts where heat load would be high or when performing in high  
377 ambient temperatures. This is especially prudent since an uncoupling of thermal state  
378 from thermal perception is plausible with menthol application thereby placing  
379 biophysical and behavioural thermoregulatory drivers in conflict. Using a menthol-  
380 spray of lower concentration which still induces perceptual benefits but does not alter  
381 thermoregulatory response (e.g. .05% concentration) may be a safer option to safeguard  
382 health<sup>8,11,12</sup>. Moreover, the addition of ethanol to the spray mix, which was deliberately  
383 excluded in the present and previous studies to maximise perceptual cooling through  
384 chemical stimulation and minimise physiological cooling through evaporation, may  
385 ensure the perceptual and thermoregulatory responses converge<sup>20</sup>.

386

### 387 **Practical Applications**

388

389 Menthol-spray application triggers heat gain responses which could increase risk of  
390 heat illness in some circumstances and care should be taken with the concentration and  
391 frequency of application. The performance benefit of menthol-spray could be extended  
392 to other population groups (i.e untrained persons) and activities where perceptions are  
393 partially limiting. However, this must be balanced against the logistical burden to  
394 carrying and deploying the spray.

395

### 396 **Conclusion**

397

398 Repeated menthol-spray application is ergogenic in trained participants during cycling  
399 in hot conditions. The perceptual benefits of repeated menthol spraying are likely to be  
400 dependent on thermal profile with a diminishing effect when there is an increasing  
401 contribution of visceral thermoreceptors to thermoreception; i.e. when deep body  
402 temperature is raised.

## References

1. Tucker R, Marle T, Lambert EV, Noakes TD. The rate of heat storage mediates an anticipatory reduction in exercise intensity during cycling at a fixed rate of perceived exertion. *J Physiol*, 2006, 574, 905–915.
2. Schlader ZJ, Simmons SE, Stannard SR, Mundel T. The independent roles of temperature and thermal perception in the control of human thermoregulatory behaviour. *Physiol Behav*, 2011, 103: 217-24.
3. Barwood MJ, Corbett J, Thomas K, Twentyman P. Relieving thermal discomfort: effects of sprayed L-Menthol on perception, performance and time trial cycling in the heat. *Scand J Med Sci in Sport*, 2015, S211-S218.
4. McKemy DD, Neuhausser WM, Julius D. Identification of a cold receptor reveals a general role for TRP channels in thermosensation. *Nature*, 2002, 416, 52-58.
5. Peier AM, Moqrich A, Hergarden AC, Reeve AJ, Andersson DA, Story GM *et al.* A TRP channel that senses cold stimuli and menthol. *Cell*, 2002, 108, 705-15.
6. Macpherson LJ, Hwang SW, Miyamoto T, Dublin AE, Patapoutian A, Story GM. More than cool: promiscuous relationships of menthol and other sensory compounds. *Mol Cell Neurosci*, 2006, 32, 335-343.
7. Green BG. Menthol modulates oral sensations of warmth and cold. *Physiol Behav*, 1985, 35, 427-434.
8. Barwood MJ, Corbett J, James J, White D. Early change in thermal perception is not a driver of anticipatory exercise pacing in the heat. *Br J Sports Med*, 2012, 46(13), 936-942.
9. Barwood MJ, Corbett J, White D. Spraying with 0.20% L-Menthol does not enhance 5k running performance in the heat in untrained runners. *J Sports Med Phys Fitness*, 2014, 54(5), 595-604.
10. Stevens CJ, Best R. Menthol: a fresh ergogenic aid for athletic performance. *Sports Med*, 2018, 47(6), 1035-1042.
11. Gillis DJ, House JR, Tipton MJ. The influence of menthol on thermoregulation and perception during exercise in warm, humid conditions. *Eur J Appl Physiol*, 2010, 110, 609-618.
12. Kounalakis SN, Botonis PG, Koskolou MD, Geladas ND. The effect of menthol application to the skin on sweating rate response during exercise in swimmers and controls. *Eur J Appl Physiol*, 2010, 109, 183-189.
13. DuBois D, DuBois EF (1915) The measurement of the surface area of man. *Int Arch Med*, 15, 868-81.
14. Bentley D J, McNaughton LR, Thompson D, Vleck VE, Batterham AM. Peak power output, the lactate threshold, and time trial performance in cyclists. *Med Sci Sport Exerc*, 2001, 33(12), 2077-2081.
15. Olesen BW. How many sites are necessary to estimate a mean skin temperature? In: Hales JRS, ed. *Thermal Physiology*. New York: Raven Press; 1980, 33-38.
16. Zhang H. *Human thermal sensation and comfort in transient and non-uniform thermal environments (published dissertation)*. Berkley: CA; University of California; 2003.
17. Borg GAV. Psychological bases of perceived exertion. *Med Sci Sport Exerc* 1982, 14, 377–381.

- 452 18. Gillis DJ, Weston N, House JR, Tipton MJ. Influence of daily menthol  
453 exposure on human temperature regulation and perception. *Physiol Behav*,  
454 2015, 139, 511-518.
- 455 19. Attia M, Engel P. Thermal pleasantness sensation: an indicator of  
456 thermal stress. *Eur J Appl Physiol Occup Physiol*, 1982, 50(1), 55-70.
- 457 20. Nadel ER, Horvath SM, Dawson CA, Tucker A. Sensitivity to  
458 peripheral and central thermal stimulation in man. *J Appl Physiol*, 1970, 29(5),  
459 603-609.
- 460 21. Gillis DJ, Barwood MJ, Newton PS, House JR, Tipton MJ. The  
461 influence of a menthol and ethanol soaked garment on human temperature  
462 regulation and perception during exercise and rest in warm, humid conditions.  
463 *J Therm Biol*, 2016, 58, 99-105.
- 464  
465  
466  
467  
468  
469  
470

471 **Figure Legends**

472

473 **Figure 1.** Mean (SD) TS (panel A), TC (panel B) and RPE (panel C) response at rest,  
474 during FI exercise and at TTE end in the control-spray (circles) and menthol-spray  
475 (squares) conditions; \*indicates significant difference between conditions at a given  
476 time point; --- indicates application of spray.

477

478 **Figure 2.** Mean (SD)  $T_{rec}$  (panel A) and  $T_{skin}$  (panel B) response at rest, during FI  
479 exercise and at TTE end in the control-spray (circles) and menthol-spray (squares)  
480 conditions; \*indicates significant difference between conditions at a given time point;  
481 --- indicates application of spray.

482

483

484

485

486