

1 Repeated Menthol spray application enhances exercise capacity in the heat

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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_{Max})
39 for 45-minutes before a test to exhaustion (TTE; 70% P_{Max}) 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_{skin}), rectal temperature (T_{rec}), 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⁻¹ *cf* 941 (319)mL·hr⁻¹; *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.

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58

59 **Introduction**

60

61 Exercise performance is impaired in hot conditions with fatigue occurring prematurely
62 compared to cool environments¹. 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 discomfort². Accordingly, any intervention that offsets these disturbances
65 in thermal perception may prove to be ergogenic and influence exercise behaviour³.
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^{4,5}. Although, menthol is also known to activate TRP vanilloid (TRPV) and
70 ankyrin (TRPA) receptors⁶ above temperatures of 37 °C thereby inducing warm
71 sensations⁷. 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 exertion². Menthol application induced an
79 approximate 18% increase in total work during the study where thermal stress was
80 applied through a water-perfused suit². 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 skin². However, in studies performed using ecologically valid
84 laboratory protocols^{3,8,9} an ergogenic effect has proved illusive leading to suggestions
85 that menthol-spraying may only improve thermal perception but not performance¹⁰.
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 intensity¹¹ and self-paced exercise^{3,8,9} in the heat. However, it has also been
90 shown to induce heat gain responses (i.e. vasoconstriction¹¹) and alter sweating
91 responses¹²; in the latter case at higher concentrations (i.e. 4.6%¹²). 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 not⁸. 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 not⁹. 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 time³. 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 goal¹¹ 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 factor¹⁰ (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^{3,8,9}. 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 heat¹¹, would enhance exercise performance in a subsequent TTE where heat
121 tolerance is the main limiting factor to performance (H₁). 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 (H₂).

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_{Max}) 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 ± 2 yrs; height 1.84 ± 0.1 m; body surface
140 area¹³ 2.05 ± 0.1 m² P_{Max} 362.5 ± 35.4 W) volunteered and provided written informed
141 consent. Participants were considered trained if they achieved a minimum P_{Max} of ≥ 350
142 watts¹⁴. 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_{Max} 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⁻¹
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⁻¹ 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 sites¹⁵ on the left side of the body secured by breathable tape
168 (TransporeTM,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 RPE¹⁷, 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 temperature³. 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 thereafter¹¹.
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 (η^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.

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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.

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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 $.990$, $\eta^2 = .015$).

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Insert figure 2 near here

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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_{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_{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

334 To our knowledge, this is the first study to investigate the possibility of an ergogenic
335 effect of repeated menthol application using an ecologically valid protocol and a
336 menthol concentration similar to those commercially available. The fact that repeated
337 menthol application is required to produce an ergogenic effect provides a challenge to
338 performers of sports where a weight bearing component may be limiting to their
339 performance (e.g. running, tour cycling). A decision to carry and deploy menthol must
340 be balanced against any performance decrement induced by bearing the additional
341 weight. Moreover, our evidence that the perturbation in thermal perception was lesser
342 after the second menthol spray application also suggests that repeated chemical
343 stimulation of the skin may have limitations especially in a hot environment. Indeed,
344 we speculate that repeated menthol application is likely to have a lesser effect because
345 of acute habituation to the sensation¹⁸ or because of an increased contribution of raised
346 deep body temperature to thermoreception thereby reducing the contribution T_{skin}
347 makes to thermal perception¹⁹. Even in the scenario of hot skin and a normothermic
348 deep body temperature, menthol may evoke warm sensations if the mean T_{skin} is over
349 37°C which has been shown in isolated cells to activate warm sensitive thermoreceptors
350 TRPA and TRPV⁶. In the present study, activation of these thermoreceptors by menthol
351 may also contribute to the lessened perceptual effect with repeated application.
352 Consequently, a combination of peripheral and visceral thermoreceptor stimulation
353 may be a more viable target for performance enhancement rather than visceral or
354 peripheral alone. There is good evidence that menthol ingestion is performance
355 enhancing¹⁰ and we show here it is premature to conclude that topical application is
356 not. It is now also plausible that topical menthol application could be ergogenic in other
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 RPE³.

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 application¹². 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 elsewhere¹² 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^{11,12}. Although we did not see the latter, we also
369 saw evidence that T_{skin} was lowered after menthol-spray application (see figure 2B)
370 indicating possible vasoconstriction. Any change in T_{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 increases²⁰.
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^{8,11,12}. 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 converge²⁰.

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.

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471 **Figure Legends**

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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.

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