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1 **Skin application of 4% menthol enhances running performance**
2 **in hot and humid climate**

3
4 **Running head:** Skin menthol and external cooling: similar effect on performance

5
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35 **Abstract**

36 Aerobic performance is negatively impacted by tropical climate due to impairment of
37 thermoregulatory mechanisms. We tested the hypothesis that a torso application of a 4%
38 menthol solution would have the same effect on a best performance 10-km run as an external
39 use of cold water. Thirteen trained male athletes completed four outdoor 10-km runs
40 ($T=29.0\pm 1.3^{\circ}\text{C}$, relative humidity $59.0\pm 13.6\%$) wearing a tee-shirt soaked every 2-km either
41 in a cold ($\sim 6^{\circ}\text{C}$) or warm/ambient ($\sim 28^{\circ}\text{C}$) solution, consisting in water or in a 4% menthol
42 solution, (CTL, MENT-Amb, CLD and MENT-CLD). Run performances were improved
43 from 4.8 to 6.1% in CLD ($51.4\pm 5.5\text{min}$), MENT-Amb ($52.2\pm 5.9\text{min}$) and MENT-CLD
44 ($51.4\pm 5.1\text{min}$) conditions (vs. CTL, $55.4\pm 8.4\text{min}$, $P<0.05$), without differences between these
45 three conditions, whereas heart rate ($177\pm 13\text{bpm}$), body temperature ($38.7\pm 0.6^{\circ}\text{C}$) and drink
46 ingestion ($356\pm 170\text{g}$) were not modified. Thermal sensation after running was lower in
47 MENT-CLD (vs. CTL, $P<0.01$) and thermal acceptability was higher in CLD and MENT-
48 Amb (vs. CTL, $P<0.05$), but thermal comfort, feeling scale and rate of perceived exertion
49 remained unchanged. The use of menthol on skin enhances aerobic performance in a tropical
50 climate, and no differences in performance were observed between menthol and traditional
51 percooling strategies. However, combining both menthol and traditional percooling brought
52 no further improvements.

53

54

55

56 INTRODUCTION

57 Hot and humid climate decreases physical performances, especially in aerobic sports [1].
58 Although the mechanisms leading to these alterations are not fully understood, it is well
59 established that thermoregulatory system dysfunction is involved into the loss of ability to
60 dissipate excess metabolic heat production [2]. These mechanisms, already impaired in hot
61 environment are further altered in humid climate, which drastically limits evapotranspiration
62 due to water-saturated atmosphere [3]. Hence, running may be the most impacted sport by
63 tropical climate as heat dissipation by circulating air convection around the body, as in
64 cycling, is reduced [4]. To limit its effect in endurance sports and to enhance
65 thermoregulatory processes, several countermeasures have been studied with various
66 outcomes on performance: acclimation, hydration, pacing and cooling strategies [1].

67 Among the latter, external cooling solutions exist in the form of pads containing low-
68 temperature inserts and may be applied on different body parts such as arms, legs, torso and
69 neck [5]. Used before (pre-) or during (per-) exercise, they allow better performance in hot
70 and humid environment by limiting the raise of body core temperature [6]. For example,
71 performances from sprints to short distance running (until 5 km) are enhanced by wearing ‘ice
72 vests’ during warm-up [7], and the use of a cooled neck-collar augments the limit time to
73 exhaustion at aerobic sub-maximal intensity [8]. Performances are further improved when
74 methods are combined (pre- and per-) [9] and/or used with more “aggressive” cooling
75 temperature, around 0°C [6]. Indeed, the disequilibrium between heat production and heat
76 loss during a prolonged exercise, leading to hyperthermia, has a negative impact on
77 physiological functions and exercise performance: heat-dissipating mechanisms (skin
78 vasodilatation, sweating response) are not enough to maintain an optimal body core
79 temperature. Strategies relying on pre- (before exercise) and percooling (during) then
80 augment heat storage and diminish the thermoregulatory strain.

81 Beyond traditional approaches of body cooling, efficient in laboratory-controlled environment
82 but difficult to use in ecological conditions, alternative strategies have been recently
83 developed to maximize performance in tropical conditions. One of them is menthol, a
84 compound largely used in food and tobacco industries, and popular in Asia for its therapeutic
85 properties [10]. It mostly acts on TRPM8 and TRPA1 thermoreceptors [11] on skin and
86 internal mucous membranes: when activated by menthol on skin, they induce a local cold
87 sensation, prone to modify thermal sensation, especially in hot environment [12], leading to a
88 reduced fatigue perception during maximal and submaximal exercise, and potentially to better
89 performances [13,14]. These preliminary observations should have led to further comparisons
90 between the respective uses of menthol and external proven cooling. However, to our

91 knowledge, there is no study directly comparing the use of menthol at ambient temperature on
92 skin and traditional cooling strategies, to test if menthol could allow the same level of
93 performance in ecological hot and humid environment, without the equipment burden. In
94 other conditions, in a laboratory-controlled environment (34°C, RH 30%), there was no
95 difference of performance between the use of cold 4% menthol gel on skin and cold pads,
96 both applied around the heat-sensitive neck compared to control condition [15]. Barwood et
97 al. showed no difference in running performance between sprayed 0.05% menthol and water
98 at 20°C [16].

99 Hence, in the lack of data comparing skin-applied menthol and cold-water cooling, as aerobic
100 performance is potentially reduced by the neurosensitive perception of environmental heat
101 and humidity, we hypothesize that the use of menthol on skin would blunt these perception
102 inhibition mechanisms and lead to enhanced performances, similar to the external use of cold
103 water for body cooling.

104

105 **SUBJECTS AND METHODS**

106 **Subjects.**

107 Thirteen middle to well trained and heat-acclimatized male athletes, with a performance level
108 from 3 to 4 out of 5 [17], participated in this study (age: 21 ± 4 years, height: 176 ± 6 cm,
109 body mass: 70 ± 9 kg, maximal aerobic speed 16.2 ± 1.3 km.h⁻¹). All participants went under
110 prior medical examination to check for any cardiopulmonary disease or previous heat stroke,
111 and were tested for their maximal aerobic speed [18]. The study was approved by the National
112 Ethic Committee (CPP, registration number 2018-A00295-50) and subjects gave their
113 informed consent. Procedures were conformed ethics in sport and exercise science [19].

114

115 **Experimental design**

116 The protocol was conducted in ecological conditions: participants in this field study ran
117 outside, on a flat paved road, directly exposed to the tropical heat and humidity of French
118 West Indies (WBGT: 29.0 ± 1.3 °C, relative humidity 59.0 ± 13.6 %), as any athletes would be
119 confronted in endurance races held in the same environment.

120 Subjects completed four 10-km run tests as fast as they could on a flat course, 4 to 7 days
121 apart, in a randomized cross-over design including four experimental conditions in which
122 athlete's shirt would be soaked in four different solutions: (1) Control (CTL): water at
123 ambient temperature ($T = 28.7 \pm 2.9$ °C); (2) Cold water (CLD) at low temperature ($T = 6.0 \pm$
124 0.8 °C); (3) Menthol at ambient temperature (MENT-Amb): 4% menthol solution at ambient
125 temperature ($T = 28.2 \pm 2.3$ °C); and (4) Menthol at low temperature (MENT-CLD): 4%

126 menthol solution at cold temperature ($T = 6.1 \pm 0.6^{\circ}\text{C}$). The menthol solutions were prepared
127 from an 86% menthol-concentrated menthol solution (Robertet, Grasse, France) which was
128 diluted to obtain a 4% solution. Athletes were asked to restrain from training the day before
129 the tests and avoid caffeine on test day. For every athlete, trials were undertaken at the same
130 time of the day to limit both variations of wet bulb globe temperature (WBGT) throughout the
131 day and circadian variations of core temperature. Finally, athletes were asked to wear the
132 same outfit at all sessions, except the white shirt provided by the experimenter.

133

134 **Experimental procedure**

135 Heart rate (HR), stride rate and run duration were recorded continuously (sampling frequency
136 1 sec) using a M400 Polar watch appaired with a H7 strap belt or a OH1 sensor [20,21] (Polar
137 Electro Oy, Kempele, Finland). WBGT was continuously measured during the trials with a
138 HD32.2 device (Delta Ohm, Padoue, Italia), placed immediately next to the run course. Core
139 temperature (T_{co}) was telemetrically measured via ingestible temperature measurement pills
140 (BodyCap, Caen, France), with an embedded memory (sampling frequency 30 sec): athletes
141 were instructed to ingest these pills 6 to 8 h before trials to ensure the pill was out of the
142 stomach, thereby avoiding changes in T_{co} due to fluid consumption. Each trial included a prior
143 15 to 20 minutes standardized warm-up. After 5 minutes of gear equipment and weighing,
144 they started the 10-km run on the 1-km out-and-back course. At start, and every 2 km, athletes
145 stopped for 30 to 40 seconds, during which: 1) athletes took their shirt off; 2) the
146 experimenter soaked it in a solution corresponding to the tested condition (CTL, CLD,
147 MENT-Amb or MENT-CLD), adding or renewing between 250 and 300 g of solution in tee-
148 shirt fabric; 3) athletes put back their shirt on; 4) athletes could hydrate *ad libitum* with water
149 at ambient temperature ($T = 26.9 \pm 1.6^{\circ}\text{C}$). The 2-km stops were necessary due to the
150 pronounced sweating rate in the hot and humid condition, which would drip the solution off
151 the shirt and blunt its potential effects. Finally, psychological parameters were assessed via
152 oral or written questionnaires immediately before start: feeling scale (FS, from -5 ‘Very bad
153 to +5 ‘Very good) [22], thermal comfort (TC, from -3 ‘Very uncomfortable’ to +3 ‘Very
154 comfortable’) [23], thermal sensation (TS, from -3 ‘Very cold’ to +3 ‘Very hot’) [24], thermal
155 acceptability (TA, from -1 ‘Clearly unacceptable’ to +1 ‘Clearly acceptable’) [25]; and after
156 the race: FS, TC, TS, TA and rate of perceived exertion (RPE, from 6 ‘Very, very light’ to 20
157 ‘Very, very hard’) [26–28].

158

159 **Data collection and statistical analyses**

160 Following the guidelines of the National Ethic Committee, the different run conditons were
161 strictly randomized to avoid effects of trial order. Run duration, HR and stride rate data were
162 measured and averaged on the successive 2-km intervals and on the whole run, and were
163 retrieved from Polar platform website. T_{co} values were telemetrically updated and
164 downloaded at the end of each session from monitors. Using calibrated balances (Terraillon,
165 Croissy-sur-Seine, France), athletes were weighed-in, dry, shoes and shirt off, immediately
166 before and after each run and water consumption (g) was measured after each stop: water loss
167 during the run was then calculated by adding the weight variation to the quantity of consumed
168 water, and the percentage of weight loss was extracted using initial body weight.
169 Psychological parameters were compiled before and after each run. Normality of data on each
170 condition was verified by a Kolmogorov-Smirnov test. Thus, repeated measures ANOVAs
171 were conducted with Condition (i.e., CTL, CLD, MENT-Amb, MENT-CLD) as the between-
172 factor and Time (i.e., 2-km intervals) as the within-factor. Posthoc Student t-tests were
173 performed when applicable, to compare mean values between successive intervals ([0-2 km]
174 vs. [2-4 km], [2-4 km] vs. [4-6 km], [4-6 km] vs. [6-8 km] and [6-8 km] vs. [8-10 km]) to
175 assess the kinetics of the run pace throughout the 10-km course, and between conditions.
176 Finally, the effect size was assessed by computing the Hedge's g when applicable. Statistical
177 significance was set at $P < 0.05$.

178

179

180 **RESULTS**

181 Results are presented in table 1 and in figures 1 and 2.

182

183 -----Insert Figure 1-----

184

185 *Environmental conditions*

186 WBGT and relative humidity are presented in table 1. There was no difference between
187 conditions.

188

189 *10 km performance (fig. 1A)*

190 Athletes were faster in CLD (- 6.1 %), MENT-Amb (- 4.8%) and MENT-CLD (- 6.1 %) when
191 compared with control ($P < 0.05$, $g = 0.55$, 0.44 , 0.57 respectively). However, no differences
192 were observed between MENT-Amb, MENT-CLD and CLD (fig. 1A).

193

194 *2 km intervals*

195 Interval splits (i.e., running performance) increased for all conditions ($P<0.01$, fig. 1A),
196 meaning that athletes were getting slower throughout the run.

197 There was a condition effect on 2-km splits ($P<0.01$, fig. 1A). No differences were observed
198 between conditions on the first two intervals. From the [4-6 km] interval to the last, split
199 durations were longer in CTL (vs CLD, Ment-Amb and Ment-CLD, $P<0.05$, fig. 1A and 1B).

200 Interval splits continuously increased from the start in CTL condition ([0-2 km] vs. [2-4 km],
201 $P<0.05$; [2-4 km] vs. [4-6 km], $P<0.001$; [4-6 km] vs. [6-8 km], $P<0.01$) before stabilizing on
202 the two last intervals. In CLD, Ment-Amb and Ment-CLD, after some pace variations (or not),
203 speed was not modified on the last three intervals ([4-6 km], [6-8 km] and [8-10 km]).

204

205 *Heart Rate*

206 No differences were observed between conditions (fig. 1C and 1D).

207

208 -----Insert Figure 2-----

209

210 *Stride Rate*

211 Stride rate was not modified by condition (fig. 2A and 2B).

212

213 *Core temperature*

214 T_{co} increased throughout the run ($P<0.001$), for each condition (fig. 2D, $P<0.001$). However,
215 there was no difference between conditions (fig. 2C).

216

217 -----Insert Table 1-----

218

219 *Perceptual measures*

220 At the end of the run, FS, TS, TC and TA were all lower ($P<0.001$ and $g=1.12$, $P<0.05$ and
221 $g=0.40$, $P<0.001$ and $g=0.71$, and $P<0.05$ and $g=0.44$, respectively) compared to the trial start.

222 TS at the end of the run was lower in MENT-CLD vs. CTL, and vs. CLD ($P<0.01$, $g=1.23$ and
223 1.22 respectively). Similarly, TA was increased in CLD, MENT-Amb (vs. CTL, $P<0.05$,
224 $g=0.74$ and 1.04 respectively) (table 1). Condition had an effect on TA ($P<0.05$, table 1).

225 RPE, FS and TC were not modified by conditions (table 1).

226

227 *Drink ingestion (table 1)*

228 Fluid ingestion increased throughout the run ($P<0.01$), although there was no difference in
229 drink ingestion between immediate successive intervals. However, some differences could be

230 observed between intervals [0-2 km] and [4-6 km] (CLD, $P<0.01$; Ment-CLD, $P<0.05$), and
231 between [0-2 km] and [6-8 km] (Ment-CLD, $P<0.001$).

232 Condition had no effect on drink ingestion.

233

234 *Weight loss (table 1)*

235 As expected, participants were lighter at the end of the run ($P<0.001$), but conditions had no
236 effect on weight loss nor on weight loss percentage.

237

238

239 **DISCUSSION**

240 Our main finding points out that the use of menthol on skin in men enhances aerobic
241 performance in a hot and humid climate, and that there is no difference in performance gain
242 between menthol and traditional percooling strategy; core temperature was not raised by a
243 faster pace, and menthol brought a lower thermal sensation. However, combining both
244 menthol and percooling did not bring any further improvements.

245 First, overall performance was positively impacted by cold and menthol conditions whereas
246 Barwood reported no difference between menthol and water sprays (at ambient temperature)
247 in run speed on a 5-km run held in hot and humid environment [16]. In a laboratory-
248 controlled study, an only acute applying of an 8% menthol gel on the face increased the time
249 limit in a high intensity exercise by more than 20% in a time-to-exhaustion tests on ergometer
250 [13], demonstrating a positive effect of menthol on performance.

251 Second, run speed decreased continuously from the start in CTL condition (fig. 1A and 1B),
252 which did not happen in the other conditions. In the study of Barwood et al.[16], there was no
253 difference in performance between conditions and athletes' speed remained steady during the
254 5-km run, whereas we found a negative effect of time on performance during our longer run.
255 Moreover, HR (fig. 1C and 1D) and core body temperature (fig. 2C and 2D) remained stable
256 between conditions (fig. 1C and 1D), even if athletes were performing better, which was also
257 reported in other works [14,16,26,29,30]. As for the heat-related perception measures,
258 participants felt the same lower TS at the end of the run than reported in other works
259 [13,16,26,27,31] while TC was also decreased [32] or maintained/augmented [13,16,26,27]
260 (table 1). It is confirmed here by a better acceptability of the heat both in cold and menthol
261 conditions. RPE was not modified by menthol, meaning that subjects performed all the tests
262 with the same maximal perceived intensity whereas run duration was better for some
263 conditions: this therefore suggests an existing enhancing-performance effect in these
264 conditions [31]. The underlying physiological mechanisms are still to be fully understood, but

265 the type of activity (running, cycling) or the environmental conditions (dry or humid heat)
266 might play a role.

267 In our study, cold water cooling and 4% menthol produced a similar effect on performance:
268 the first strategy is long-known to buffer and help dissipate the excess metabolic-heat [6]
269 whereas the second modifies the perception of the environmental heat and humidity [33]. Our
270 study design also allowed us to study the effects of separate (CLD, Ment-Amb) and combined
271 (Ment-CLD) conditions, but we found no further improvement of the latter compared to CLD
272 or Ment-Amb taken separately, as an additive effect could have been expected. This
273 underlines a limit in the combination of multiple strategies to maintain a thermal homeostasis
274 when exercising in a tropical climate. If the effect of external cooling is well understood,
275 mainly by augmenting the heat capacity, the mechanisms elicited by the internal or external
276 use of menthol remain to be fully understood.

277 The absence of difference in T_{co} between conditions (fig. 2C) implies that, at a faster pace, the
278 thermoregulatory system would have to dissipate a greater amount of metabolic heat. If we
279 assume that the low temperature solutions ($\sim 6^{\circ}\text{C}$) soaking the tee-shirt in CLD and MENT-
280 CLD conditions were able to absorb a portion of the excess heat, this mechanism was not
281 possible in the MENT-Amb condition, as the solution temperature remained above 28°C .
282 Regarding the non-modified T_{co} in all conditions, this raises interrogations about the
283 functioning of thermoregulatory mechanisms, already impaired by the humid atmosphere, and
284 by the limited cooling by air convection during running [2]. Moreover, this excess of heat
285 could not be evacuated through the process of water ingested / loss of water (sweat), as there
286 was no difference, on one hand, between environment and beverage temperatures (heat
287 capacity), and on the other hand, between weight loss in the different conditions (physically
288 evacuated heat through sweat). If aerobic performance strongly depends on core temperature
289 and by its capacity to dissipate excess heat, an alternative mechanism may play a key role in
290 thermoregulation under these harsh conditions, here potentially triggered by menthol applied
291 on skin. This mechanism could be related to the effect of menthol on peripheral blood
292 circulation. A first study reported a skin vasoconstriction when a 3.5% menthol gel was
293 applied on skin [34], which was only noted only during the first 5 min after application. In
294 more recent studies, a vasodilatation phenomenon was observed from 5 min after application
295 and was maximal between 15 and 45 min; a dose-dependent activation was also recorded,
296 optimal from 4 to 7% concentration [35], associated with a proportional related-cold sensation
297 [36]. These menthol-related mechanisms in peripheral vasodilatation would activate, other
298 than TRPM8 thermoreceptors [11], multiple vasodilator pathways, such as nitric oxide (NO)
299 and endothelium-derived hyperpolarizing factor (EDHF), hence increasing blood flow.

300 Although these studies were performed at rest in thermoneutral conditions, these recent
301 advances could lead to further studies in order to assess these effects at exercise, in hot/humid
302 environment. This opening could also bring a novel light to the central governor model [37],
303 regulating afferent and efferent mechanisms to prevent the occurrence of bodily harm, for
304 example by adjusting race pace under a high thermal stress. Whereas the cold sensation
305 elicited by the use of menthol would act on the central governor through thermosensitive
306 afferences and therefore “trick” it into adopting a higher exercise intensity [38], locally NO-
307 mediated and EDHF actions would promote a cutaneous vasodilatation to counteract a greater
308 metabolic heat production. This would lead to a higher core temperature, and therefore
309 maintain a system homeostasis as long as possible, or as long as the central command is under
310 the influence of TRPM8 afferences. Regarding core temperature, it’s noticeable that
311 numerous previous studies using menthol reported no increase in T_{co} [14,16,26,29,30]. This
312 could be interpreted as a defense mechanism, peripherally triggered, and would compensate a
313 dysfunction from the central command potentially leading to body harm. Moreover, although
314 experimental conditions were designed to preserve a single-blind protocol, it was possible that
315 the aroma from menthol impregnated in the tee-shirt fabric would reach the respiratory
316 system through the nasal passages. As inhaled menthol provokes a large increase of
317 ventilation at rest and exercise [39], an additional heat loss could be made through the
318 augmented respiratory process [40].

319 Finally, as menthol promotes a higher exercise intensity through sensory nerve-dependent
320 mechanisms [38], our TS data confirm a significant cooling sensation felt by athlete after the
321 run, as observed in other works [13,16,26,27,33,34], potentially acting on central command.
322 This is also confirmed in our study by a higher TA in MENT-Amb condition (vs. CTL,
323 $P<0.05$, table 1). However, we did not observe changes in TC (table 1), unlike other works
324 [16,26,27,34]. To summarize, when using menthol in tropical climate, athletes ran faster and
325 felt “comfortably fresher” than in CTL condition.

326 In conclusion, our works show improved 10-km performance in ecological conditions when
327 using a 4% menthol skin application. This enhancement was the same as using cold water or
328 cold menthol. The use of a higher menthol concentration (4%) than those used in most studies
329 underlines a dose effect of menthol, while physiological parameters, such body core
330 temperature and heart rate, did not show further impaired thermal stress compared to control
331 condition. The underlying mechanisms are not fully understood yet, but recent findings on
332 menthol-related cutaneous vasodilatation open new perspectives of research and bring a novel
333 light on the central governor theory. Regarding the potential physiological mechanisms
334 induced by the application of menthol on skin, future studies may focus on the effects of

335 different concentration of menthol on aerobic performance, especially in long-duration
336 running.

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437 **Captions**

438 **Figure 1**

439 A and B: overall run duration in CTL, CLD, MENT-Amb and MENT-CLD conditions (upper
440 panel: A, individual values and mean \pm SD) and by 2 km-interval per condition for each
441 condition (lower panel: B, mean \pm SEM).

442 C and D: average heart rate in CTL, CLD, MENT-Amb and MENT-CLD conditions (upper
443 panel: C, mean \pm SD) and by 2 km-interval per condition for each condition (lower panel: D,
444 mean \pm SEM).

445 *: $P < 0.05$, CLD/MENT-Amb/MENT-CLD vs. CTL.

446 Time effects were not reported for readability.

447

448 **Figure 2**

449 A and B: average stride rate in CTL, CLD, MENT-Amb and MENT-CLD conditions (upper
450 panel: A, mean \pm SD) and by 2 km-interval per condition for each condition (lower panel: B,
451 mean \pm SEM).

452 C and D: average core temperature in CTL, CLD, MENT-Amb and MENT-CLD conditions
453 (upper panel: C, mean \pm SD) and by 2 km-interval per condition for each condition (lower
454 panel: D, mean \pm SEM).

455 Time effects were not reported for readability.

456

457

458 **Table 1**

459 Mean values (\pm SD) of rate of perceived exertion (RPE, from 6 'Very, very light' to 20 'Very,
460 very hard'), feeling scale (FS, from -5 'Very bad to +5 'Very good), thermal sensation (TS,
461 from -3 'Very cold' to +3 'Very hot'), thermal comfort (TC, from -3 'Very uncomfortable' to
462 +3 'Very comfortable'), thermal acceptability (TA, from -1 'Clearly unacceptable' to +1
463 'Clearly acceptable'), ingested drink and percentage of weight loss.

464 * $P < 0.05$, ** $P < 0.01$: vs. CTL

465 ++ $P < 0.01$: vs. CLD

466 † $P < 0.05$: vs. MENT-AMB

467

468 **Table 1**

469 Mean values (\pm SD) of environmental condition (WBGT and relative humidity RH) rate of perceived exertion (RPE, from 6 ‘Very, very light’ to 20
 470 ‘Very, very hard’), feeling scale (FS, from -5 ‘Very bad’ to +5 ‘Very good’), thermal sensation (TS, from -3 ‘Very cold’ to +3 ‘Very hot’), thermal comfort
 471 (TC, from -3 ‘Very uncomfortable’ to +3 ‘Very comfortable’), thermal acceptability (TA, from -1 ‘Clearly unacceptable’ to +1 ‘Clearly acceptable’),
 472 ingested drink and percentage of weight loss.

473 *P<0.05, **P<0.01: vs. CTL

474 ++P<0.01: vs. CLD

475 †P<0.05: vs. MENT-AMB

		CTL	CLD	MENT-AMB	MENT-CLD
Environmental conditions	WBGT (°C)	29.1 \pm 1.5	28.9 \pm 1.2	28.8 \pm 1.5	29.1 \pm 1.2
	RH (%)	57.7 \pm 12.9	60.0 \pm 13.4	63.6 \pm 14.5	54.6 \pm 13.3
RPE (n.u.)		15.8 \pm 2.2	14.5 \pm 3.1	14.6 \pm 1.8	15.6 \pm 1.7
FS (n.u.)	Pre	2.0 \pm 2.0	2.3 \pm 2.1	2.5 \pm 2.1	1.9 \pm 2.3
	Post	-0.8 \pm 2.3	0.1 \pm 2.3	0.7 \pm 2.0 *	-0.9 \pm 1.7 †
TS (n.u.)	Pre	1.2 \pm 0.9	0.7 \pm 0.9	1.0 \pm 0.8	1.1 \pm 1.0
	Post	1.2 \pm 1.4	1.1 \pm 0.9	0.0 \pm 1.7	-0.4 \pm 1.2 ** ++
TC (n.u.)	Pre	0.5 \pm 0.7	0.6 \pm 0.6	0.8 \pm 0.7	0.6 \pm 0.8
	Post	-0.5 \pm 1.2	-0.1 \pm 1.2	0.3 \pm 0.9	0.2 \pm 0.6
TA (n.u.)	Pre	0.3 \pm 0.4	0.3 \pm 0.3	0.5 \pm 0.3	0.3 \pm 0.4
	Post	-0.1 \pm 0.5	0.2 \pm 0.4 *	0.4 \pm 0.5 *	0.2 \pm 0.5
Drink ingested (g)		363 \pm 173	367 \pm 162	318 \pm 164	379 \pm 198
% weight loss		-1.3 \pm 0.8	-1.0 \pm 0.6	-1.4 \pm 1.0	-1.2 \pm 0.6

476

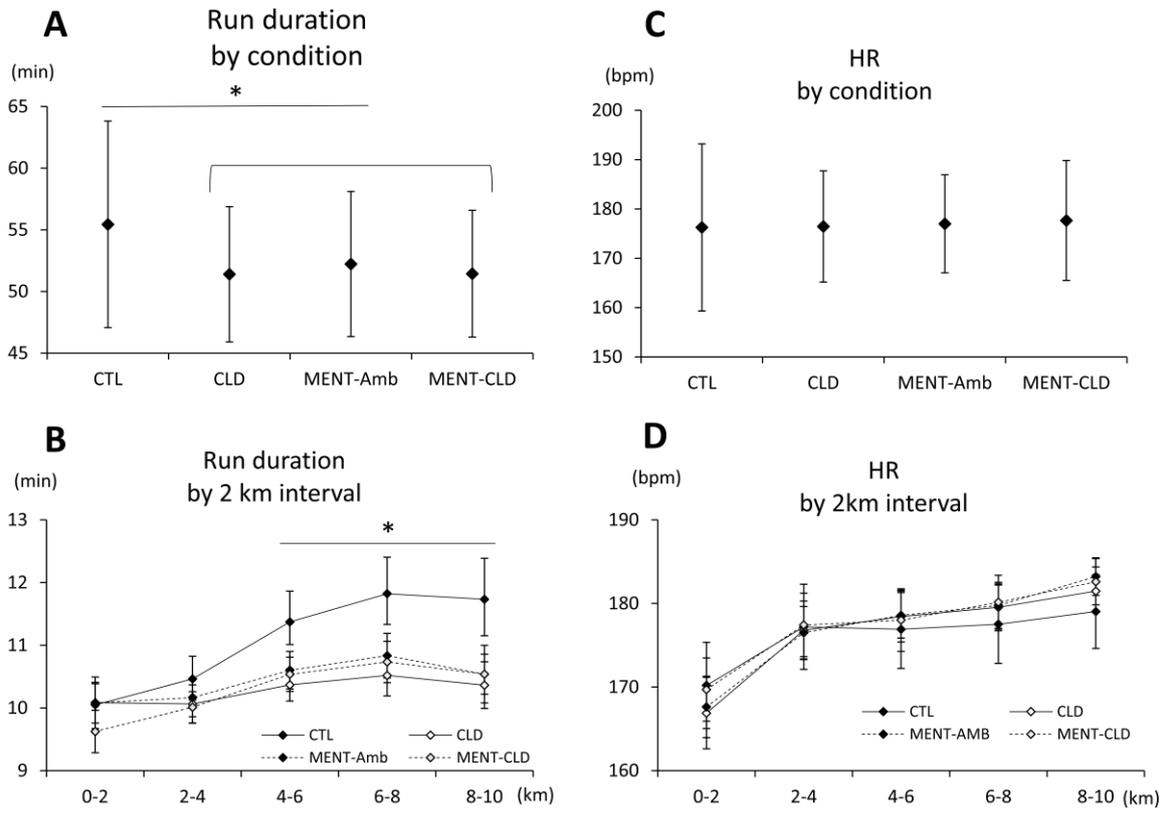


Figure 1

477

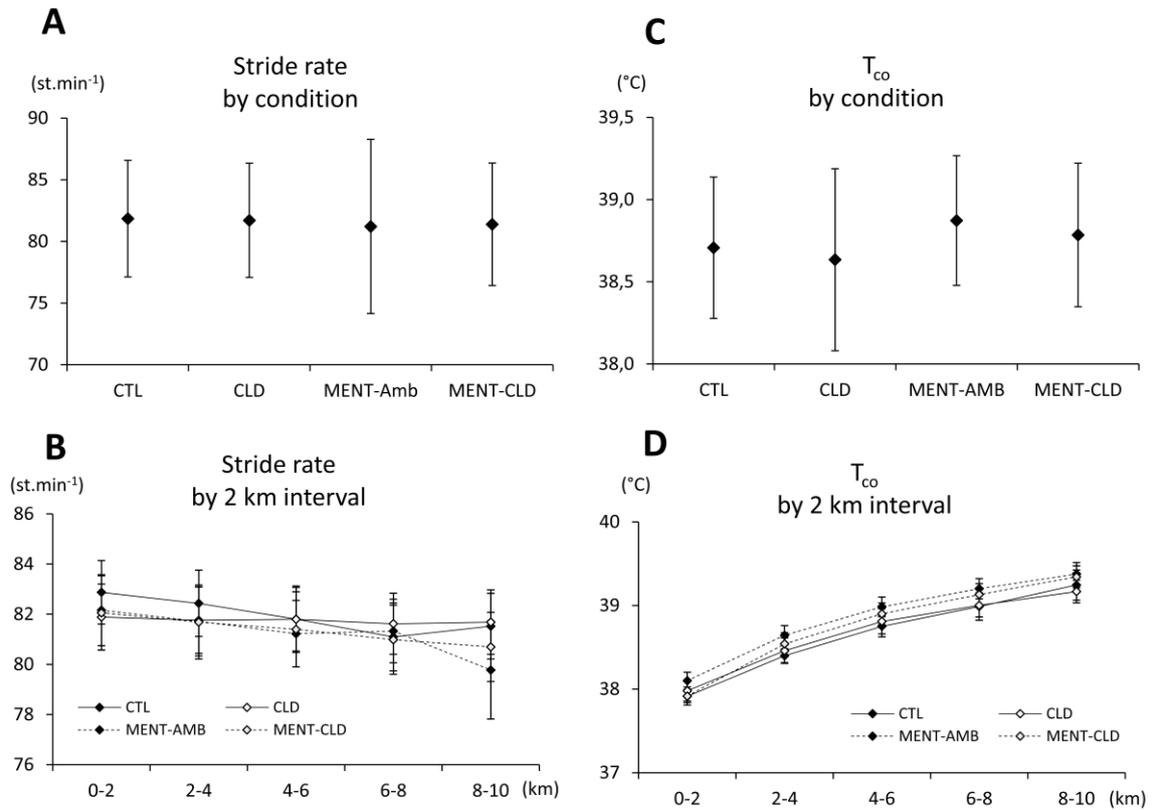


Figure 2

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479