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# Practical Torso Cooling During Soccer-Specific Exercise in the Heat

## Kirstie Parris, MSc; Christopher J. Tyler, PhD

Department of Life Sciences, University of Roehampton, Whitelands College, London, United Kingdom

**Context:** Precooling and midevent cooling of the torso using cooling vests can improve exercise performance in the heat with or without physiological changes; however, the effects of such cooling during intermittent exercise in the heat are unknown.

**Objective:** To investigate the effects of torso cooling during intermittent exercise in the heat (35°C, 50% relative humdity) on sprint performance and the physiological and perceptual responses to the exercise.

Design: Crossover study.

Setting: Walk-in environmental chamber.

**Patients or Other Participants:** Ten non–heat-acclimated, male soccer players (age =  $25 \pm 2$  years, height =  $1.77 \pm 0.06$  m, mass =  $72.9 \pm 7.6$  kg).

*Intervention(s):* Two 90-minute bouts of soccer-specific intermittent running in the heat: 1 trial with a cooling vest worn during the exercise and 1 trial without a cooling vest. Each trial comprised two 45-minute periods separated by approximately 15 minutes of seated rest in cool conditions (approximately 23°C, 50% relative humdity).

**Main Outcome Measure(s):** Peak sprint speed, rectal temperature ( $T_r$ ), mean-weighted skin temperature ( $T_{sk}$ ), heart rate (HR), rating of perceived exertion (RPE), and thermal sensation (TS) were measured every 5 minutes.

**Results:** Peak sprint performance was largely unaffected by the cooling vest. The T<sub>r</sub>, T<sub>sk</sub>, HR, RPE, and TS were unaffected in the cooling-vest trial during the first 45 minutes, but T<sub>r</sub> rose at a slower rate in the cooling-vest trial ( $0.026^{\circ}C \cdot min^{-1} \pm 0.008^{\circ}C \cdot min^{-1}$ ) than in the no-vest trial ( $0.032^{\circ}C \cdot min^{-1} \pm 0.009^{\circ}C \cdot min^{-1}$ ). During the second 45-minute period, T<sub>r</sub>, T<sub>r</sub> rate of rise, T<sub>sk</sub>, RPE, and TS were lower in the cooling-vest trial (Hedges *g* range, 0.55–0.84), but mean HR was unaffected.

**Conclusions:** Wearing a cooling vest during soccer-specific intermittent running in the heat reduced physiological and perceptual strain but did not increase peak sprint speed.

*Key Words:* cooling vest, ice vest, football, intermittent exercise, cryotherapy, hyperthermia

Key Points

- Percooling using a cooling vest during intermittent soccer-specific exercise in the heat did not improve repeatedsprint performance at the investigated environmental temperatures.
- Percooling lowered physiological and perceptual strain, so a cooling vest may help soccer players participating in training, warm-ups, or practice matches in the heat.

any major soccer tournaments are played in hot, humid countries; therefore, soccer players are often required to perform prolonged, highintensity, intermittent exercise in temperatures approaching or exceeding 30°C (eg, 2016 Union of European Football Associations European Championship, France; 2019 Fédération Internationale de Football Association Copa América, Brazil; 2022 Fédération Internationale de Football Association World Cup, Qatar). Playing in elevated temperatures, such as these, can pose a threat to health and impair high-intensity sprint and soccer performance<sup>1-4</sup> due to greater actual<sup>5,6</sup> and perceived<sup>7,8</sup> thermal strain. Minimizing the health risks and the reduced performance observed in high ambient temperatures would be attractive to athletes and coaches, so interventions that might reduce actual or perceived thermal strain or both, such as cooling garments, are sought.<sup>9,10</sup>

Cooling before exercise (*precooling*) can improve subsequent exercise performance and capacity in the heat with and without physiological alterations<sup>11</sup>; however, precooling interventions vary in practicality. Cooling vests, which are used by many elite sporting teams,<sup>12</sup> are among

the more practical precooling interventions because they are ergonomically designed, are portable, and cover a large surface area of the body, but data regarding their effectiveness in practical scenarios are equivocal. Precooling using cooling vests can lower core body and skin temperatures, reduce heart rate (HR), and improve the perceptions of task difficulty and thermal comfort.<sup>13-16</sup> However, not all vests offer a sufficiently prolonged cooling effect to induce such changes,<sup>16,17</sup> so cooling strategies applied during exercise may be an option to consider. Cooling vests worn during exercise (percooling) can improve exercise capacity during heat stress<sup>18-20</sup>; yet they may effectively reduce physiological strain only when the magnitude of heat stress is very high (eg, when an individual is encapsulated in a nuclear, biological, chemical suit).<sup>19</sup> Short-duration (approximately 30-minute) cycling capacity is improved in the heat when wearing a cooling vest<sup>18</sup> largely due to reductions in perceived, rather than actual, physiological strain, but the effect of cooling during more prolonged intermittent exercise is unknown.

Soccer match percooling might be a practical and effective way to maintain performance and minimize the

health risks of competing in the heat.<sup>21</sup> Soccer rules do not permit players to wear cooling vests during competition, but if such garments are effective and safe, they could be worn during warm-ups, training sessions, and noncompetitive soccer games held in hot, humid conditions. Therefore, the purpose of our study was to investigate the effects of wearing a cooling vest on sprint performance and the physiological and perceptual responses to the exercise during soccer-specific intermittent running in the heat.

### METHODS

### **Participants**

Ten physically active, non-heat-acclimated male soccer players (age =  $25 \pm 2$  years, height =  $1.77 \pm 0.06$  m, mass  $= 72.9 \pm 7.6$  kg) volunteered. We defined *physically active* as participating in at least 2 bouts of soccer-specific training and one 90-minute soccer match each week. We defined non-heat acclimated as having no exposure to temperatures greater than 25°C for at least 10 days before the study. Participants were fully informed of any risks and discomforts associated with the study before completing a health screen questionnaire.<sup>22</sup> The health screen questionnaire was completed before each laboratory visit and evaluated by the investigators to ensure that the health status of the participant had not changed. Participants abstained from consuming alcohol and engaging in strenuous exercise for 24 hours before all trials. They arrived at the laboratory approximately 30 minutes before the trial, approximately 1.5 hours after drinking 500 mL of water, and more than 2 hours postprandial. Adherence to these requirements was orally verified before all trials, and no violations were reported. All participants provided written informed consent, and the study was approved by our university's Ethical Advisory Committee.

### **Experimental Procedures**

Participants visited the laboratory on 3 occasions: 1 familiarization session and 2 experimental trials. Experimental trials were conducted in a randomized, crossover order at the same time of day ( $\pm 30$  minutes) and at least 6 days apart. All trials took place in a walk-in environmental chamber (model WIR52-20HS; Design Environmental Ltd, Gwent, United Kingdom) controlled at a temperature of  $35.1^{\circ}C \pm 0.2^{\circ}C$  and relative humidity of  $50.2\% \pm 0.5\%$ . During the familiarization trial, participants performed repeated maximal sprints on a nonmotorized treadmill (Woodway Curve; Vor DEM, Auf Schrauben, Germany) until they reported feeling habituated and then completed one 45-minute block of a soccer-specific intermittentrunning protocol. During each experimental trial, participants completed two 45-minute bouts of a soccer-specific intermittent-running protocol performed on a motorized treadmill (Pulsar; h/p/cosmos sports & medical, Nussdorf-Traunstein, Germany) separated by a 15-minute seated rest in temperate conditions (approximately 23°C, 50% relative humidity). Each participant wore a soccer shirt, shorts, socks, and athletic shoes during the trials. In 1 experimental trial, participants wore a commercially available cooling vest (model 6626M-PEV Kewl Fit Performance Enhancement Cooling Vest; TechNiche International, Vista, CA) throughout both 45-minute bouts; in the other trial, they did

not wear a cooling vest. Participants drank water ad libitum during each trial; the volume consumed was recorded. The water bottles were initially refrigerated and then allowed to warm to room temperature during the trial. Body mass was recorded before and after each experimental trial, and these data were combined with the fluid-consumption data to estimate sweat loss and sweat rate.

### Soccer-Specific Intermittent-Running Protocol

Participants completed a 10-minute standardized warmup comprising a 5-minute jog at 8 km  $h^{-1}$  followed by 5 minutes of self-selected stretching. Next, they completed a 90-minute laboratory-based, intermittent-running treadmill protocol designed to replicate the demands of soccer, as used previously.<sup>23</sup> The exercise protocol consisted of two 45-minute halves separated by a 15-minute passive rest undertaken outside the chamber in a comfortable temperature (approximately 20°C). Each 45-minute half consisted of three 15-minute blocks of soccer-specific activity repeated consecutively. The proportion of time spent on each activity and corresponding treadmill speed were as follows: 3.8% rest at 0 km  $\cdot$  h<sup>-1</sup>, 27.9% walking at 4 km  $\cdot$  h<sup>-1</sup>, 38.9% jogging at 8 km·h<sup>-1</sup>, 19.9% cruising at 10 km·h<sup>-1</sup>. and 9.8% sprinting at a self-paced maximal effort. Walking, jogging, and cruising were performed on a motorized treadmill with a 1% gradient, whereas the maximal sprint was performed on a nonmotorized treadmill located adjacent to the motorized treadmill (transition time between treadmills <10 s). For each activity, we used the order, speed, and duration described by Clarke et al<sup>23</sup> with the following adjustments: (1) the jogging and cruising speeds were reduced from 12 km·h<sup>-1</sup> and 15 km·h<sup>-1</sup>, respectively, after pilot work demonstrated that the participants were unable to complete the trials at the original speeds; (2) the order of activities was altered to ensure that 1 sprint was performed every 5 minutes (ie, sprints were performed as shown in Figure 1 of Clarke et  $al^{23}$  with the following 2 changes: the third sprint was the 10th rather than the 11th action, and the seventh sprint was the 27th rather than the 26th action); and (3) sprints were self-paced. The peak sprint speed (PSS) was recorded from every fifth-minute sprint.

### **Physiological and Perceptual Variables**

Rectal temperature  $(T_r)$  was measured using a rectal thermistor (model REC-U-VL3-0; Grant Instruments [Cambridge] Ltd, Shepreth, Cambridgeshire, United Kingdom) self-inserted approximately 10 cm past the anal sphincter. Skin thermistors (model EUS-U-VL-3; Grant Instruments [Cambridge] Ltd) were attached to the participant using a transparent dressing (Tegaderm; 3M Health Care, St Paul, MN) and waterproof tape (Transpore; 3M Health Care). We estimated the mean-weighted skin temperature  $(T_{sk})$  by calculating the T<sub>sk</sub> at 4 sites (sternum, right forearm, right anterior thigh, and right posterior calf) using the equation of Ramanathan.<sup>24</sup> Heart rate was measured using a chest monitor (model T31; Polar Electro Oy, Kempele, Finland). Rating of perceived exertion (RPE) was measured using a scale ranging from 6 (no exertion) to 20 (maximal exertion),<sup>25</sup> and thermal sensation (TS) was rated using a 9-point scale ranging from 0 (unbearably cold) to 8 (*unbearably hot*), with 4 (*neutral*) as comfortable.<sup>26</sup> The



Figure 1. Peak sprint speeds during the soccer-specific intermittent-sprint protocol with and without a cooling vest (mean  $\pm$  standard deviation). <sup>a</sup> Difference between trials (Hedges g > 0.5).

area under the curve (AUC) and rate of rise (ROR) were calculated for the temperature data. Data were recorded at 5-minute intervals.

### **Cooling-Vest Trial**

The cooling vest was applied immediately after the warm-up and was worn on top of the participant's soccer shirt throughout the first 45-minute bout of exercise. It was removed at the start of the 15-minute break and replaced with a new cooling vest at the end of the break before the participant re-entered the climatic chamber. The second cooling vest was worn throughout the second 45-minute bout of exercise. Each cooling vest had 4 pockets, covering both the anterior and posterior sections of the torso, in which 4 sealed packets (378 g) of frozen phase-change cooling inserts (n-hexadecane and n-tetradecane) were inserted. The cooling vest with inserts weighed 1752 g. It covered 28.4%  $\pm$  1.8% of estimated body surface area (BSA), but not all of this was cooled; the activated phasechange cooling inserts covered approximately  $8.3\% \pm$ 0.5% of the estimated BSA.<sup>27</sup>

### **Statistical Analyses**

Parametric data are presented as mean  $\pm$  standard deviation, and nonparametric data are presented as median (range). For parametric data, 2-way repeated-measures

analyses of variance (trial  $\times$  time or trial  $\times$  half) were conducted to compare the differences in sprint data,  $T_r$ ,  $T_{sk}$ , and HR between trials (cooling vest, no vest). Post hoc Bonferroni tests were conducted to identify pairwise differences when appropriate. Hedges g effect sizes were calculated to determine the magnitude of differences between trial pairings. For the perceptual data, we ran Friedman analyses of variance and Wilcoxon signed rank tests and calculated r effect sizes. The likelihood that the true value of the effect represented a worthwhile change was assessed using the following thresholds: *trivial* (<0.1), small (0.1–0.3), moderate (0.3–0.5), large (0.5–0.7), and *very large* (>0.7) for *r* and *trivial* (<0.2), *small* (0.2–0.5), moderate (0.5–0.8), and large (>0.8) for Hedges g.<sup>28</sup> For clarity, only moderate, large, and very large effects are reported, and these are accompanied by mean differences and 95% confidence intervals (CIs). We used SPSS (version 21.0; IBM Corp, Armonk, NY) for the statistical analysis. The  $\alpha$  level was set at  $\leq .05$ .

### RESULTS

### **Sprint Performance**

The PSS data were similar between trials. We observed no main effect of cooling ( $F_{1,7} < .001, P = .98$ ) or half ( $F_{1,7} = 2.5, P = .12$ ) or cooling-by-half interaction effect ( $F_{1,7} = .001, P = .001$ )



Figure 2. Rectal temperature during the soccer-specific intermittent-sprint protocol with and without a cooling vest (mean  $\pm$  standard deviation). <sup>a</sup> Difference between trials (Hedges g > 0.5).

0.2, P = .84; Figure 1). The PSS was higher in the 45th minute (mean difference [95% CI] = 2.49 km·hr<sup>-1</sup> [0.25 km·hr<sup>-1</sup>, 4.72 km·hr<sup>-1</sup>]; Hedges g = 0.71) but was unaffected at all other times.

### Physiological and Perceptual Variables

Physiological and perceptual data are reported in Figures 2 through 4 and in the Table. Pre-exercise  $T_r$  was similar in the cooling-vest  $(37.0^{\circ}C \pm 0.2^{\circ}C)$  and no-vest trials  $(36.9^{\circ}C \pm 0.3^{\circ}C)$ , and T<sub>r</sub> increased over time in both trials (P < .001). The ROR was greatest during the no-vest trial in the first (P = .004, Hedges g = 0.67) and second (P =.009, Hedges g = 0.75) 45-minute bouts, resulting in a lower T<sub>r</sub> in the cooling-vest trial at 40 (mean difference  $[95\% \text{ CI}] = -0.2^{\circ}\text{C} [-0.5^{\circ}\text{C}, 0.1^{\circ}\text{C}]; \text{ Hedges } g = 0.51), 45$ (mean difference [95% CI] =  $-0.2^{\circ}$ C [ $-0.5^{\circ}$ C,  $0.1^{\circ}$ C]; Hedges g = 0.68), and 60 to 90 minutes (mean difference range  $[95\% \text{ CI}] = -0.3^{\circ}\text{C}$  to  $-0.2^{\circ}\text{C}$   $[-0.6^{\circ}\text{C}$  to  $0.0^{\circ}\text{C}]$ ; Hedges g range, 0.68–1.54; Figure 2). Mean T<sub>r</sub> was not different in the first half, but the cooling vest had a moderate effect in lowering mean  $T_r$  during the second half and lowering ROR and AUC during both halves (Table). The cooling vest also had a moderate effect in lowering mean  $T_r$  (mean difference [95% CI] =  $-0.16^{\circ}C$  [ $-0.34^{\circ}C$ ,  $0.01^{\circ}C$ ]; P = .14; Hedges g = -0.68) and T<sub>r</sub> AUC (mean difference [95% CI] =  $-0.99^{\circ}C \cdot min^{-1}$  [ $-1.34^{\circ}C \cdot min^{-1}$ ,

 $0.64^{\circ}$ C·min<sup>-1</sup>]; P = .002; Hedges g = -0.94) during the 90-minute bout.

Pre-exercise  $T_{sk}$  was similar between trials (34.2°C ± 0.7°C in both trials) and increased over time in both trials (P < .001). During the first half, the cooling vest had no effect on mean  $T_{sk}$  (P = .90) or ROR (P = .92), resulting in similar AUCs (P = .83). The  $T_{sk}$  was lower during the cooling-vest than the no-vest trial during the second half (P = .007, Hedges g = 0.51; Figure 3), but ROR (P = .39) and AUC were similar (P = .39).

The HR increased over time (P < .001) and was similar between trials overall (P = .59) and in the first (P = .53) and second halves (P = .72; Figure 4).

Overall, median RPE and TS were lower in the coolingvest than the no-vest trial (RPE = 13 [range, 6–18] versus 13 [range = 6–20], respectively; mean difference [95% CI] = -0.9 [-2.2, 0.3]; P < .001, and TS = 5 [range = 1–7] versus 6 [range, 3–8], respectively; mean difference [95% CI] = -0.7 [-1.3, 0.0]; P = .003) largely due to reductions in the second 45-minute bout (P < .001, r = 0.52 for both; Table). The cooling vest had no effect on RPE (P = .18, r =0.16) or TS (P = .62, r = 0.06) during the first half.

### Fluid Balance

We observed no differences between trials for pretrial body mass (cooling vest =  $72.9 \pm 7.5$  kg, no vest =  $72.9 \pm$ 



Figure 3. Mean-weighted skin temperature during the soccer-specific intermittent-sprint protocol with and without a cooling vest (mean  $\pm$  standard deviation). <sup>a</sup> Difference between trials (Hedges g > 0.5).

7.6 kg; P = .50) or fluid consumption (cooling vest = 0.71 ± 0.15 L, no vest = 0.71 ± 0.16 L; P = .88). The cooling vest had a moderate effect in lowering sweat loss (cooling vest = 1.74 ± 0.26 L, no vest = 2.10 ± 0.66 L; mean difference [95% CI] = -0.36 L [-0.73, 0.00 L]; P = .09; Hedges g = 0.68) and sweat rate (cooling vest = 1.15 ± 0.17 L·hr<sup>-1</sup>, no vest = 1.40 ± 0.44 L·hr<sup>-1</sup>; mean difference [95% CI] = -0.24 L·hr<sup>-1</sup> [-0.49, 0.00 L·hr<sup>-1</sup>]; P = .09, Hedges g = 0.68).

### DISCUSSION

To our knowledge, we are the first to investigate the effects of wearing a cooling vest during intermittent exercise in the heat. Sprint performance was largely unaffected by cooling; only the final sprint of the first half was improved. Wearing a cooling vest slowed the ROR in  $T_r$  without altering other physiological or perceptual variables during the first half and lowered actual and perceived thermal strain during the second 45-minute bout.

The ability to sustain high-intensity, repeated sprints is required for successful soccer performance; however, in elevated temperatures, the ability to perform such activity is impaired.<sup>2–4</sup> Investigators have reported that precooling or midevent cooling or both using a cooling vest had little effect on high-intensity, intermittent exercise (Cohen d < 0.3)<sup>9,29,30</sup> and that meaningful benefits were observed only

when the cooling vest was supplemented with other cooling methods, such as water immersion, ice towels, and ice packs.<sup>30</sup> Our data suggested that percooling using a cooling vest during high-intensity, intermittent exercise in the heat also had little effect on overall sprinting performance. The highest PSS during the first half was observed in the 45th minute of the cooling-vest trial and in the 20th minute of the no-vest trial, suggesting that participants in the former trial adopted a slightly different pacing strategy when instructed to maximally sprint in the first 45 minutes, starting slower and finishing faster than in the latter trial. The slight disruption may have been due, at least in part, to the extra approximately 1.75 kg of mass worn during the cooling-vest trial that would have increased the energy cost of the activity.<sup>13</sup> A performance benefit may have been observed if participants had worn an uncooled vest rather than no vest during the no-vest trial; however, such a comparison would likely overstate any true benefit because wearing uncooled garments is not normal practice and can impair performance when compared with cooled equivalents due to discomfort and a lack of physiological and perceptual benefits.<sup>31</sup> Previous data<sup>6,9,15</sup> have suggested that an inverse relationship exists between core body temperature and intermittent-sprint ability; however, in our study, PSS was greatest in the 90th minute of the intermittentsprint protocol during both trials, when core temperatures were at their highest (Figures 1 and 2). It is not uncommon



Figure 4. Heart rate during the soccer-specific intermittent-sprint protocol with and without a cooling vest (mean  $\pm$  standard deviation).

for participants to spurt at the end of self-paced activities when they know that no further efforts will be required.<sup>32</sup>

The cooling vest lowered  $T_r$  for most of the protocol, with the greatest half-specific differences observed during the last 15 minutes of each half. Effect sizes were small for the first 25 minutes of the protocol, possibly due to the short duration between applying the cooling vest and beginning exercise (<5 minutes). A longer precooling period may have had a greater effect on lowering core body temperature; however, a longer or more severe cooling intervention before exercise may raise  $T_r$  due to the after-drop phenomenon.<sup>33</sup> In our study, whereas reductions in T<sub>sk</sub> indicated that surface cooling occurred, an after-drop was not observed, likely due to the relatively low magnitude and gradual cooling offered by the cooling vest that avoided a pronounced vasoconstriction response. Mean-weighted, rather than site-specific,  $T_{sk}$  was measured; that is, none of the thermistors were located under the cooling vest. Mean T<sub>sk</sub> was lower during the second half in the cooling-vest trial largely due to a greater reduction during the 15-minute break, which resulted in a lower  $T_{sk}$  at the start of the second half. In the 2 previous studies<sup>18,20</sup> in which researchers investigated the effect of wearing a cooling vest during exercise, T<sub>r</sub> and T<sub>sk</sub> were unaffected. The cooling vest cooled a similar BSA (approximately 5% of BSA,<sup>18</sup> approximately 8% of BSA [our study], and approximately 10% of BSA<sup>20</sup>), so the different observations are likely due to different methodologic approaches. Participants in the study conducted by

Luomala et al<sup>20</sup> wore a cooling vest for approximately 45 minutes, but it stopped cooling after approximately 30 minutes. Therefore, it is likely to have become insulative after this time, whereas in the study by Cuttell et al,<sup>18</sup> participants exercised for only approximately 30 minutes. We observed the greatest differences after 30 minutes and minimized any insulative concerns by removing the cooling vest at the end of the first 45 minutes and replacing it with a newly cooled one at the start of the second 45 minutes.

Median RPE and TS were lower in the cooling-vest than the no-vest trial largely due to reductions in the second 45 minutes (first-half data were similar). In this case, the perceptual data aligned with the physiological data; the greatest reductions in both actual and perceived strain were observed during the second 45 minutes of the protocol. A lower TS has been reported in the cooling-vest percooling literature,<sup>18–20</sup> but reductions in RPE have been reported only in an encapsulated heat-stress study.<sup>19</sup> Decreased perceived thermal state is an important regulator of prolonged selfpaced exercise in the heat,<sup>34</sup> so it is likely that the benefit of percooling would be more pronounced using a protocol with more self-paced components or using a cooling vest capable of causing a greater or earlier reduction in TS, or both.

### **Limitations and Future Directions**

We did not measure the magnitude of cooling provided by the cooling vest, and this is a common limitation of the

int Protocol With and Without a Cooling Vest	Second Half
of the Soccer-Specific Intermittent-Spr	Half-Time
the First Half, Half-Time, and Second Half	First Half
Physiological and Perceptual Data From	
Table.	

		FIRST Hall		Halt-III	ne		Second Ha	Ц
	Cooling Vest	No Vest	Mean Difference	Cooling Vest	No Vest	Cooling Vest	No Vest	Mean Difference
Variable	Mean	± SD	(95% CI)	Mean ±	SD	Mean	+ SD	(95% CI)
Rectal temperature	00 + 0 20	C C + F 0C			0 0 + 	30 C + F 0C	00 + 0 00	0 21 / 0 16 0 01/
Rate of rise. °C·min⁻¹	37.6 ± 0.2 0.026 ± 0.008 <sup>b,d</sup>	30.1 ± 0.2 0.032 ± 0.009	-0.09 (-0.26, 0.1) -0.006 (-0.009, -0.004)	−0.0 H 0.4	-0.7 - 0.3	$30.1 \pm 0.2^{-12}$	0.022 ± 0.006	-0.24 (-0.46, 0.01) -0.004 (-0.006, -0.001)
Area under the curve, °C·min <sup>-1</sup>	3.1 ± 1.1 <sup>b,d</sup>	3.6 ± 1.0	-0.64 (-0.87, -0.41)			$1.9 \pm 0.6^{d,e}$	$2.2 \pm 0.7$	-0.35 (-0.64, -0.06)
Mean-weighted skin temperature								
Mean, °C	$35.3 \pm 0.6$	$35.2 \pm 0.4$	0.01 (-0.20, 0.21)	$-2.9\pm0.5^{\rm d,e}$	$-2.4 \pm 0.8$	$34.7 \pm 0.6^{b,d}$	$35.0 \pm 0.4$	-0.34 (-0.51, -0.16)
Rate of rise, °C·min⁻¹	$0.035 \pm 0.013$	$0.036 \pm 0.012$	-0.001 ( $-0.005$ , $0.004$ )			$0.056 \pm 0.016$	$0.051 \pm 0.022$	0.005 (-0.006, 0.016)
Area under the curve, °C·min <sup>-1</sup>	$3.9 \pm 1.4$	$4.0~\pm~1.3$	-0.06 (-0.61, 0.48)			$6.3 \pm 1.8$	$5.8\pm2.5$	0.58 (-0.66, 1.82)
Mean heart rate, beats min <sup>-1</sup>	141 <u>+</u> 16	$137 \pm 20$	4 (-7, 14)	-55 ± 7	-51 ± 18	$142 \pm 14$	141 ± 21	2 (8, 11)
	Median	(Range)		Median (F	lange)	Median (	Range)	
Median thermal sensation, arbitrary								
units	6 (3–7)	6 (4–8)	0.1 (-0.7, 1.0)	$-2 (-4 \text{ to } -2)^{d,e}$	0 (-5 to 0)	5 (1–7) <sup>b,c</sup>	6 (3–8)	-0.7 (-1.3, 0.0)
Median rating of perceived exertion,								
arbitrary units <sup>a</sup>	12 (6–15)	12 (9–16)	-0.2 (-1.3, 0.8)			13 (6–18) <sup>b,c</sup>	14 (6–19)	-0.9 (-1.9, 0.0)
Abbreviation: CI, confidence interve	аІ.							
<sup>a</sup> Range = 6 to 20.								
<sup>b</sup> Different from control group at the	e same time point	( <i>P</i> < .01).						
<sup>c</sup> Large effect ( $r > 0.5$ , Hedges $g >$	> 0.8).							

<sup>d</sup> Moderate effect (r = 0.3-0.5, Hedges g = 0.5-0.8). <sup>e</sup> Different from control group at the same time point (P < .05).

precooling and percooling literature.<sup>11</sup> Whereas it is likely that the  $T_{sk}$  under the cooling vest was lowered,<sup>9,18</sup> this variable should be measured in future percooling studies. In addition to measuring the cooling magnitude offered by the vest, investigators should more closely measure and match hydration status between trials to ensure that the effect of cooling alone can be more effectively assessed.

The ability to sustain high-intensity, repeated sprints is required for successful soccer performance, but it is not the sole requirement. Players must execute soccer-specific skills and make complex decisions throughout a match. Some indirect data have suggested that cooling may improve such actions,<sup>35</sup> but we did not measure this. Authors of a position statement<sup>21</sup> have suggested that soccer-match percooling might be a practical, effective way to maintain performance and minimize the health risks of competing in the heat. Whereas our study offers some support for the health component of this suggestion (eg, moderately lowers thermal strain), more work focusing on percooling and soccer-specific skill performance (eg, passing, shooting, decision making) is required.

Percooling the torso can reduce the physiological and perceptual strain experienced during intermittent exercise in the heat; however, it did not improve repeated sprint performance in the heat. The lack of performance benefit may be due, at least in part, to the increased energy cost of running while wearing the cooling vest. The cooling vest increased the load that the participants were carrying by approximately 1.75 kg, and this would have increased the energy cost of the activity. Arngrimsson et al<sup>13(p1868)</sup> investigated the effects of a heavier (approximately 4.5kg) cooling vest worn during a warm-up and reduced running speed by approximately 0.8 km hr<sup>-1</sup> "to compensate for the extra metabolic work done ... due to the weight of the vest." The extent to which the cooling vest increased the energy cost of the exercise is unknown and could have been determined using a third trial in which participants wore an uncooled vest of the same mass; however, comparing a cooled with an uncooled vest may overstate any performance benefit because athletes would not perform activity while wearing an uncooled vest, and authors<sup>31</sup> of the cooling literature who have compared cooled and uncooled garments have reported performance impairments.

### **Practical Applications**

Despite the lack of performance benefit in our study, the reduced physiological and perceptual strain would be of interest to coaches and athletes alike when trying to maximize training volume in hot conditions while maintaining athletes' well-being and comfort. A percooling reduction in physiological and perceptual strain would be particularly useful when athletes have little time to prepare for competing in the heat (eg, a sudden fixture change or a sudden heat wave); however, percooling should be avoided if full heat adaptation is desired because heat acclimatization requires elevated thermal strain and a sufficient thermal impulse.

### CONCLUSIONS

Percooling using a cooling vest during intermittent soccer-specific exercise did not improve overall repeatedsprint performance at the environmental temperatures that we investigated. It can lower physiological and perceptual strain during such activity, so a cooling vest may assist soccer players undertaking training, warm-ups, or practice matches in the heat.

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Address correspondence to Christopher J. Tyler, PhD, Department of Life Sciences, University of Roehampton, Whitelands College, Danebury Avenue, London, SW15 4JD, United Kingdom. Address e-mail to chris.tyler@roehampton.ac.uk.