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Cooling Rates of Hyperthermic Humans Wearing American Football Uniforms When Cold-Water Immersion Is Delayed

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Context: Treatment delays can be contributing factors in the deaths of American football athletes from exertional heat stroke. Ideally, clinicians begin cold-water immersion (CWI) to reduce rectal temperature (T_{rec}) to <38.9°C within 30 minutes of collapse. If delays occur, experts recommend T_{rec} cooling rates that exceed 0.15°C/min. Whether treatment delays affect CWI cooling rates or perceptual variables when football uniforms are worn is unknown.

Objective: To answer 3 questions: (1) Does wearing a football uniform and delaying CWI by 5 minutes or 30 minutes affect T_{rec} cooling rates? (2) Do T_{rec} cooling rates exceed 0.15°C/min when treatment delays have occurred and individuals wear football uniforms during CWI? (3) How do treatment delays affect thermal sensation and Environmental Symptoms Questionnaire responses?

Design: Crossover study.

Setting: Laboratory.

Patients or Other Participants: Ten physically active men (age = 22 ± 2 y, height = 183.0 ± 6.9 cm, mass = 78.9 ± 6.0 kg).

Intervention(s): On 2 days, participants wore American football uniforms and exercised in the heat until T_{rec} was 39.75°C. Then they sat in the heat, with equipment on, for either 5 or 30 minutes before undergoing CWI (10.6°C ± 0.1°C) until T_{rec} reached 37.75°C.

Main Outcome Measure(s): Rectal temperature and CWI duration were used to calculate cooling rates. Thermal sensation was measured pre-exercise, postexercise, postdelay, and post-CWI. Responses to the Environmental Symptoms Questionnaire were obtained pre-exercise, postdelay, and post-CWI.

Results: The T_{rec} cooling rates exceeded recommendations and were unaffected by treatment delays (5-minute delay = 0.20°C/min ± 0.07°C/min, 30-minute delay = 0.19°C/min ± 0.05°C/min; P = .4). Thermal sensation differed between conditions only postdelay (5-minute delay = 6.5 ± 0.6, 30-minute delay = 5.5 ± 0.7; $P < .05$). Environmental Symptoms Questionnaire responses differed between conditions only postdelay (5-minute delay = 27 ± 15, 30-minute delay = 16 ± 12; $P < .05$).

Conclusions: Treatment delays and football equipment did not impair CWI's effectiveness. Because participants felt cooler and better after the 30-minute delay despite still having elevated T_{rec}, clinicians should use objective measurements (eg, T_{rec}) to guide their decision making for patients with possible exertional heat stroke.

Key Words: Environmental Symptoms Questionnaire, exertional heat stroke, rectal temperature, thermal sensation

Key Points

- Treatment delays and football equipment did not impair cold-water immersion's effectiveness.
- If treatment delays occur in patients with possible exertional heat stroke, clinicians should implement cold-water immersion.

American football players are a population that is especially at risk for exertional heat illnesses such as heat exhaustion and exertional heat stroke (EHS).[1,2] Secondary school American football players had an 11 times higher risk of developing exertional heat illnesses than players in all other sports combined.[2] Sadly, 146 American football players have died from EHS in the last 84 years.[1] However, morbidity and mortality can be lowered if rectal temperature (T_{rec}) is used to confirm the EHS diagnosis and whole-body cold-water immersion (CWI) is used to reduce T_{rec} to <38.9°C within 30 minutes of collapse.[3] If EHS treatment has been delayed, experts[4] recommended that cooling rates exceed 0.15°C/min.

Extensive delays in EHS diagnosis or treatment (or both) can be disastrous for athletes.[5] Treatment delays may occur because of a lack of medical personnel (eg, athletic trainers) present to quickly recognize EHS symptoms,[6] misdiagnosis of EHS,[7] athlete noncompliance, difficulty removing equipment before CWI, or use of inappropriate treatments (eg, fanning) to lower T_{rec}.[8] Recent research[9,10] showed excellent T_{rec} cooling rates (>0.21°C/min) when American football uniforms were worn during CWI. Although these findings relieved the concern about having to remove equipment before initiating CWI, other reasons for treatment delays could still result in catastrophe. In fact, the longer body core temperature remains >40.5°C, the higher the likelihood of multiorgan dysfunction and cell death.[11]

Few scientists have examined the body's response to treatment delays after mild exercise-induced hyperthermia.

Flouris et al[12] observed that CWI T_{rec} cooling rates were unaffected by treatment delays as long as 40 minutes. Although their study[12] was well designed, it had 2 main limitations. First, their participants wore minimal clothing and a rain poncho covering the torso and head during testing.[12] Thus, the clinical applicability of their observations to athletic populations who wear equipment was low. Second, American football uniforms are heavier and cover more body surface area than rain ponchos. Consequently, evaporative resistance[13] and metabolic heat production[14,15] would be higher, which would result in impaired heat dissipation.[16] Thus, wearing a football uniform during treatment delays could increase body core temperature and possibly expedite cooling once CWI is initiated because of the larger thermal gradient. Alternatively, prolonged delays could result in substantial passive shell cooling,[17] which would lower the thermal gradient and result in lower T_{rec} cooling rates. Few data[14] have addressed how treatment delays affected T_{rec} when hyperthermic humans wore American football uniforms. No data existed on how wearing football uniforms after treatment delays of various lengths affected CWI cooling rates and, as a result, possible treatment timelines.

Therefore, the purpose of our study was to answer 3 questions. First, does wearing an American football uniform and delaying CWI by 5 minutes or 30 minutes affect T_{rec} cooling rates? Second, do T_{rec} cooling rates exceed 0.15°C/min when full American football uniforms (PADS) are worn during CWI and when treatment delays occur? Third, how do treatment delays affect thermal sensation and Environmental Symptoms Questionnaire (ESQ) responses when hyperthermic participants wear American football uniforms? We hypothesized that treatment delays would not affect T_{rec} cooling rates, that CWI T_{rec} cooling rates would exceed 0.15°C/min after both delays, and that perceptual responses (eg, thermal sensation and ESQ responses[18]) would be higher after the 5-minute treatment delay.

METHODS

Participants

A convenience sample of 12 healthy, recreationally active, unacclimatized men volunteered for our study. However, 1 participant could not tolerate the exercise protocol, and equipment malfunctions prevented a second participant from finishing the protocol. Thus, 10 men completed the study (Table 1). Recruits were excluded if they self-reported any of the following: (1) an injury that impaired their ability to exercise; (2) any neurologic, metabolic, gastrointestinal, respiratory, or cardiovascular disease; (3) taking any medication that could affect fluid balance or temperature regulation; (4) a *sedentary lifestyle* (defined as exercising <30 minutes, 3 times per week)[19]; (5) a history of heat-related illness in the 6 months before data collection; (6) illness at the time of data collection; or (7) any recent diarrheal illness, anal surgery, anal fistula, hemorrhoid, or anal fissure. All procedures were approved by our institutional review board, and participants provided written informed consent before testing.

Table 1. Participant Demographics and Descriptive Information[a]

Characteristic	Delay, min (Mean ± SD) 5	30
Age, y	22 ± 2	
Height, cm	183.0 ± 6.9	
Body mass index	23.6 ± 1.5	
Body density, g/cc	1.08 ± 0.01	
Body fat, %	9 ± 3	
Body surface area, m^2	2.0 ± 0.1	
Pre-exercise urine specific gravity	1.009 ± 0.006	1.003 ± 0.003
Body mass pre-exercise, kg	78.9 ± 6.0	79.1 ± 6.0
Body mass postexercise, kg	77.7 ± 6.1	77.6 ± 6.1
Sweat rate, L/h	1.5 ± 0.2	2.0 ± 0.4
Posttesting hypohydration, %	1.5 ± 0.4	1.9 ± 0.4
Environmental chamber temperature, °C	38.4 ± 0.2	38.4 ± 0.5
Environmental chamber relative humidity, %	44 ± 1	44 ± 2
Preimmersion water-bath temperature, °C	10.6 ± 0.1	10.6 ± 0.1
Postimmersion water-bath temperature, °C	11.3 ± 0.2	11.3 ± 0.2

[a] n = 10.

Procedures

Participants reported to a laboratory on 2 days separated by at least 72 hours. On the first testing day, participants randomly selected a number from a container that corresponded to the testing order (eg, an odd number meant the participant completed the 30-minute trial first). The same number of odd and even numbers was available to ensure that the experiment was counterbalanced. Participants were instructed to avoid exercise, caffeine, and alcohol for at least 24 hours before testing; maintain a consistent diet; drink water regularly throughout the day before and on the day of testing; and fast for 2 hours before testing. They self-reported compliance before testing each day.

On testing days, participants emptied their bladders completely so we could determine their hydration status (SUR-Ne refractometer; Atago USA Inc, Bellevue, WA). If the urine specific gravity was <1.020,[20] they were weighed nude. If the participant was hypohydrated, testing was rescheduled for at least 48 hours later. If the participants was euhydrated, skinfolds at the thigh, abdomen, and chest were measured (skinfold caliper model 12-1110; Fabricated Enterprises, Inc, White Plains, NY) in triplicate and averaged.[21] Skinfolds were summed and used to estimate body density[22] and percentage of body fat.[21] Body surface area was also estimated.[23]

Each participant donned a heart-rate monitor (Polar Electro Inc, Lake Success, NY) and self-inserted a thermistor (model 401; Advanced Industrial Systems, Prospect, KY) 15 cm past the anal sphincter.[24] Then, he put on PADS. Briefly, PADS consisted of shoes; socks; undergarments; athletic shorts; three-quarter–length pants with hip, knee, tailbone, and thigh padding; a T-shirt; shoulder pads; a mesh jersey; and a helmet. (For a complete description of PADS, we direct the reader to our prior work.[9,10]) The participant entered an environmental chamber and stood on a treadmill for 10 minutes to acclimate to the hot and humid environment (Table 1). After the 10-minute acclimatization period, T_{rec}, thermal sensation, and

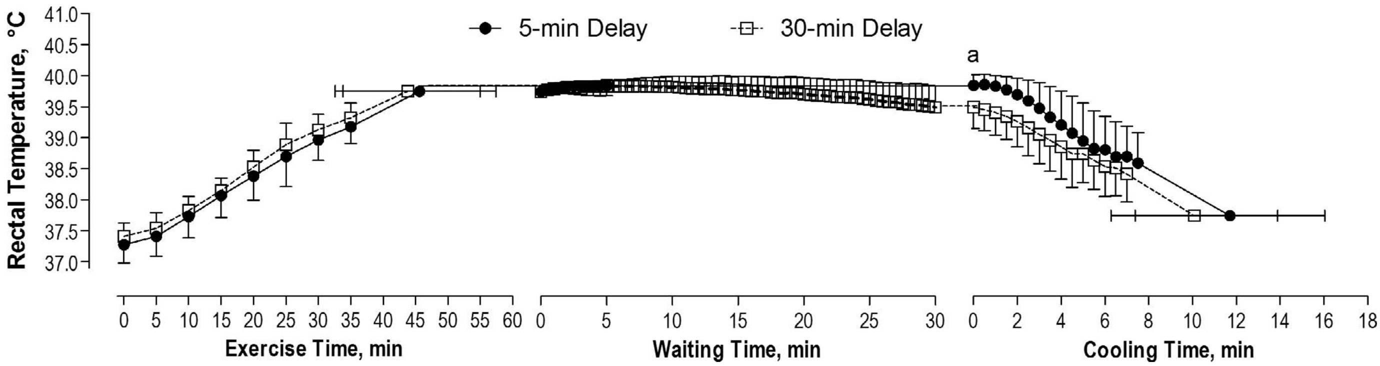

Figure 1. Rectal temperatures during exercise (left), a 5- or 30-minute wait period (middle), and cold-water immersion (CWI; right) while participants wore a full American football uniform (mean ± standard deviation, n = 10). Data are shown until the shortest exercise and water-immersion durations common to at least 80% of participants. The x-axis error bars indicate the SD for the final exercise and CWI durations. [a] Rectal temperature at the end of the 5-minute delay was higher than at the end of the 30-minute delay (*P* = .004).

ESQ scores were recorded. He then performed consecutive 5-minute exercise bouts consisting of walking at 3 mph (0% incline) for 3 minutes followed by 2 minutes of running at 90% of their age-predicted maximum heart rate. Rectal temperature was recorded every 5 minutes during exercise. Exercise continued without rest breaks or fluids until T_{rec} reached 39.75°C.

Once T_{rec} reached 39.75°C, participants stopped exercising and rated their thermal sensation. They sat on chairs inside the environmental chamber, while still wearing PADS, for either 5 minutes or 30 minutes, depending on their randomly assigned testing order. We chose the 5-minute delay because this is the approximate time needed for medical personnel to remove football equipment and obtain T_{rec} during a simulated EHS scenario.[25] The 30-minute delay was chosen because experts[4,26] have advised that EHS patients have their T_{rec} reduced to <38.9°C within 30 minutes of collapse. Rectal temperature was measured every 30 seconds during this waiting period.

After the delay, participants rated their thermal sensation a third time, completed the ESQ a second time, and removed their shoes. Then, they immersed themselves, while wearing PADS, up to the neck in a tub of cold water (~10.5°C; 1135.6-L capacity, noncirculating water tub, model 4247; Rubbermaid, Atlanta, GA). The tub was kept in the environmental chamber for the duration of testing; water temperature was continuously monitored and maintained at ~10.5°C by adding ice as necessary while participants exercised. Once the participant's foot touched the water, a standard stopwatch was started so we could determine the immersion duration. The water bath was stirred every 2 minutes and T_{rec} was recorded every 30 seconds. Participants remained immersed until T_{rec} decreased to 37.75°C.

Upon reaching a T_{rec} of 37.75°C, they exited the water bath, rated their thermal sensation a fourth time, and answered the ESQ a third time. Participants sat in the heat for 15 minutes (for safety/monitoring purposes), exited the environmental chamber, removed the football equipment and rectal thermistor, dried themselves, and were weighed nude a second time. They were then excused and asked to return at least 72 hours later for their second day of testing. No fluids were given to participants at any time during testing.

Statistical Analysis

Separate dependent *t* tests were used to determine if differences existed between the delay periods for CWI duration and T_{rec} cooling rates. The final T_{rec} measurements of the delay periods were also analyzed using a dependent *t* test to determine if T_{rec} differed between the delays immediately before CWI. We calculated repeated-measures analyses of variance to determine if differences in thermal sensation or ESQ scores existed between the delay periods over time. For the ESQ data, we summed the scores from the 16-item questionnaire for a cumulative score.[27] Sphericity was assessed with a Mauchly test. When sphericity was violated, Greenhouse-Geisser adjustments were made to *P* values and degrees of freedom. For significant interactions or main effects, we used Tukey-Kramer post hoc tests to identify differences between conditions at each time point. Significance occurred when $P < .05$ (version 2007; Number Cruncher Statistical Software, Kaysville, UT).

RESULTS

Data were reported as means and standard deviations. Pre-exercise urine specific gravity, preimmersion and postimmersion water-bath temperatures, sweat rates, environmental conditions, and posttesting hypohydration levels were not analyzed statistically but were reported for descriptive purposes (Table 1).

Participants exercised for similar durations each day (5-minute delay = 45.6 ± 11.8 minutes, 30-minute delay = 43.8 ± 11.2 minutes, $t_9 = 1.7$, $P = .12$; Figure 1). Rectal temperature at the end of the 5-minute delay (39.9°C ± 0.2°C) was higher than T_{rec} after the 30-minute delay (39.5°C ± 0.3°C; $t_9 = 3.8$, $P = .004$; Figure 1). Durations of cold-water immersion were similar between conditions (5-minute delay = 11.7 ± 4.3 minutes, 30-minute delay = 10.1 ± 3.8 minutes, $t_9 = 1.5$, $P = .16$), as were T_{rec} cooling rates (5-minute delay = 0.20°C/min ± 0.07°C/min, 30-minute delay = 0.19°C/min ± 0.05°C/min, $t_9 = 0.9$, $P = .4$).

We observed an interaction between condition and time for thermal sensation ($F_{3,27} = 7.4$, $P < .001$; Figure 2). Thermal sensation differed between conditions only post-delay ($P < .05$). However, several differences within each condition were noted over time. On the 5-minute delay day, pre-exercise thermal sensation was different from all other

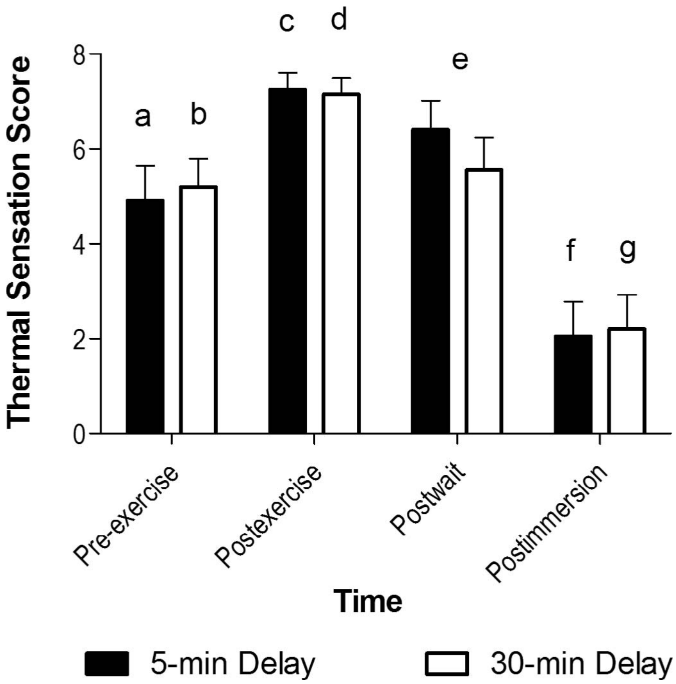

Figure 2. Thermal-sensation scores before exercise, immediately postexercise, postwait, and post–cold-water immersion (mean ± standard deviation, n = 10). Scale ratings ranged from 0 (*unbearably cold*) to 8 (*unbearably hot*). A score of 4 indicated the participant was *comfortable*. [a] Indicates 5 minutes pre-exercise different from all other 5-minute time points. [b] Indicates 30 minutes pre-exercise was different from 30 minutes postexercise and 30 minutes postimmersion. [c] Indicates 5 minutes postexercise >5 minutes postwait and 5 minutes postimmersion. [d] Indicates 30 minutes postexercise >30 minutes postwait and 30 minutes postimmersion. [e] Indicates 5 minutes postwait >30 minutes postwait. [f] Indicates 5 minutes postwait >5 minutes postimmersion. [g] Indicates 30 minutes postwait >30 minutes postimmersion. All letters indicate significance at $P < .05$.

times ($P < .05$). Postexercise thermal sensation was higher than postdelay and post-CWI thermal sensation ($P < .05$). The postdelay thermal sensation score was higher than the post-CWI scores ($P < .05$). On the 30-minute delay day, thermal sensation pre-exercise was different from that postexercise and post-CWI ($P < .05$). Postexercise thermal sensation was higher than at postdelay and post-CWI. Finally, postdelay thermal sensation was higher than at post-CWI on the 30-minute delay day ($P < .05$).

Regarding ESQ responses, we demonstrated an interaction between condition and time ($F_{1,10} = 6.3$, $P = .03$; Table 2). The ESQ responses differed between conditions only postdelay ($P < .05$). However, several differences within each condition were present. For both conditions, pre-exercise ESQ responses were lower than those at postdelay; the postdelay responses were higher than the post-CWI responses ($P < .05$).

DISCUSSION

Unfortunately, treatment delays are common during EHS scenarios,[5,7,28,29] and athlete morbidity and mortality increase the longer T_{rec} remains elevated above the threshold for cell damage (ie, 40.5°C [105°F]).[11,28] Thus, the importance of initiating CWI as quickly as possible after an EHS diagnosis cannot be overstated. Failing to lower T_{rec} to <40.5°C within 30 minutes can be catastrophic.[11] Clinicians must make all attempts to minimize the potential for and duration of treatment delays for patients with possible EHS.

Our main observation was that CWI effectively reduced T_{rec} even in the presence of treatment delays up to 30 minutes and PADS worn by mildly hyperthermic humans not experiencing EHS. Although treatment delays exacerbate hypohydration and increase cardiovascular strain (eg, decrease mean arterial pressure and stroke volume),[12] they did not impair CWI's effectiveness. Our data extend the work of Flouris et al,[12] who observed that treatment delays of 5, 20, and 40 minutes did not affect CWI T_{rec} cooling rates (0.21°C/min ± 0.03°C/min, 0.17°C/min ± 0.01°C/min, and 0.17°C/min ± 0.01°C/min, respectively). Because CWI's cooling rates often vastly exceed those of other modalities (eg, fanning, intravenous fluids),[8] clinicians must be able to perform CWI if treatment delays occur during EHS situations. Collectively, our data and those of others bolster CWI's reputation as the criterion standard treatment for EHS[4] and the modality of choice for EHS, regardless of whether treatment delays have occurred.

In the current study, CWI T_{rec} cooling rates were excellent (~0.20°C/min) and exceeded the rate experts recommended if treatment delays occur during EHS scenarios (ie, 0.15°C/min).[4,8] The fact that CWI T_{rec} cooling rates were unaffected by the wearing of football uniforms during treatment, even after brief and prolonged treatment delays, supports the main findings of 2 other experimental trials.[9,10] In these studies, T_{rec} cooling rates were 0.21°C ± 0.11°C per minute[10] and 0.28°C ± 0.12°C per minute[9] when hyperthermic participants wore football uniforms during CWI (~10°C). Clinically, this means that medical personnel do not need to delay the initiation of CWI by trying to remove football equipment. Overall, this study and past studies[9,10,30] support the National Athletic Trainers' Association's recommendation[26] that athletic equipment be removed from EHS victims after CWI is initiated.

The T_{rec} response after each delay has clinical implications. Consistent with others,[12] we observed that T_{rec} increased 0.10°C ± 0.17°C at the end of the 5-minute delay. An increase in T_{rec} is common as blood flow increases to the gut after exercise cessation.[31] Clinically, this means that if a clinician recognizes and responds to an EHS emergency within 5 minutes, it should not be surprising if T_{rec} increases or stays the same during the first few minutes of CWI. However, during the 30-minute condition, T_{rec} decreased 0.20°C ± 0.3°C (passive cooling rate of 0.008°C/min ± 0.01°C/min). Flouris et al[12] noted that T_{rec} decreased 0.43°C (passive cooling rate of ~0.011°C/min) after their 40-minute treatment delay. Others[32–34] have also demonstrated passive cooling rates ranging from 0.022°C/min to 0.04°C/min when minimal clothing was worn postexercise in thermoneutral or warm environments. Our passive cooling rates were lower because PADS increased thermal resistance and insulated the body[13] while also increasing oxygen consumption.[14] Thus, American football players will cool more slowly and may be at a higher risk of having a body core temperature remain above 40.5°C for longer periods of time.

Our final goal in this study was to determine how football equipment affected mildly hyperthermic participants'

Table 2. Environmental Symptoms Questionnaire Responses Before and After a Delay in Cold-Water Immersion (CWI)[a]

	Mean ± SD					
	5-min Delay			30-min Delay		
	Pre-Exercise	Postdelay	Post-CWI	Pre-Exercise	Postdelay	Post-CWI
Statement						
1. I feel lightheaded	0 ± 0	2 ± 1	1 ± 1	0 ± 0	2 ± 1	1 ± 1
2. I have a headache	0 ± 0	1 ± 1	0 ± 1	0 ± 0	1 ± 1	0 ± 0
3. I feel dizzy	0 ± 0	2 ± 1	1 ± 1	0 ± 0	1 ± 1	0 ± 0
4. I feel faint	0 ± 0	2 ± 1	0 ± 1	0 ± 0	1 ± 1	0 ± 0
5. My coordination is off	0 ± 0	2 ± 2	1 ± 1	0 ± 0	2 ± 1	1 ± 1
6. It is hard to breathe	0 ± 0	2 ± 1	0 ± 0	0 ± 0	0 ± 1	0 ± 0
7. I have a chest pain	0 ± 0	1 ± 1	0 ± 0	0 ± 0	0 ± 0	0 ± 0
8. I have a muscle cramp	0 ± 0	1 ± 1	0 ± 0	0 ± 0	1 ± 1	0 ± 0
9. I feel weak	0 ± 0	2 ± 2	1 ± 1	0 ± 0	2 ± 2	1 ± 1
10. I feel sick/nauseated	0 ± 0	1 ± 1	0 ± 0	0 ± 0	1 ± 1	0 ± 0
11. I feel irritable	0 ± 0	2 ± 2	0 ± 1	0 ± 0	1 ± 1	0 ± 0
12. My heart is pounding	0 ± 0	2 ± 1	0 ± 0	0 ± 0	1 ± 1	0 ± 0
13. I feel feverish	0 ± 0	2 ± 2	0 ± 1	0 ± 0	1 ± 2	0 ± 0
14. I feel warm	2 ± 2	4 ± 1	0 ± 0	1 ± 1	3 ± 1	0 ± 0
15. My vision is blurry	0 ± 0	1 ± 1	0 ± 0	0 ± 0	0 ± 1	0 ± 0
16. I feel goose bumps	0 ± 0	1 ± 1	1 ± 1	0 ± 0	0 ± 1	1 ± 1
Total	2 ± 2	27 ± 15[b,c,d]	7 ± 6	2 ± 1	16 ± 12[b,c]	5 ± 4

[a] n = 10. The Environmental Symptoms Questionnaire is rated on a 5-point Likert scale with scores ranging from 0 (*not at all*) to 5 (*extreme*). Scores at each time point were summed to create a total symptom score, which was then statistically analyzed.
[b] Different from the pre-exercise time point within the same treatment ($P < .05$).
[c] Different from post-CWI within the same treatment ($P < .05$).
[d] 5 minutes postdelay >30 minutes postdelay ($P < .05$).

perceptions of temperature and heat-illness signs and symptoms in the presence of CWI delays. Johnson et al[27] observed insignificant increases in thermal sensation but significant increases in ESQ scores immediately postexercise when mildly hyperthermic men (T_{rec} = 39.2°C) wore American football equipment. We found that both thermal-sensation and ESQ scores were lower after the 30-minute delay, indicating that participants felt cooler and had fewer signs and symptoms of heat illness than after the 5-minute delay. Interestingly, thermal-sensation scores after the 30-minute delay were similar to pre-exercise scores despite participants' having an average T_{rec} of 39.5°C. Given these results and the fact that EHS can impair mental status, it is crucial to rely on objective metrics, such as T_{rec}, rather than on how athletes feel to diagnose EHS. Fewer than 25% of athletic trainers used T_{rec} when evaluating EHS, which is troubling[35] and may suggest that other metrics are being used to guide clinical decisions during EHS scenarios.

We acknowledge the following 2 limitations of our study. First, as in many prior experimental studies[9,10,12,27] of T_{rec} cooling rates, our participants did not experience EHS. Second, our participants were not American football players, nor did they have the physical characteristics of the football players most prone to EHS (eg, higher body weights and greater amounts of body fat).[36] Future researchers may wish to examine T_{rec} cooling rates among obese or overweight athletes who experience delays in CWI to better extend these results to athletic populations.

In conclusion, CWI should be implemented as quickly as possible after an EHS diagnosis, even if treatment has been delayed and the individual is wearing PADS. Because T_{rec} cooling rates exceeded recommendations and were not affected by football equipment, clinicians should not waste further time removing equipment, especially if lengthy delays have already occurred.[26] Moreover, clinicians should not rely on subjective perceptions (eg, how hot an athlete feels) if lengthy treatment delays have occurred because these are not reliable indicators of body core temperature. Overall, clinicians must minimize treatment delays at all costs to prevent catastrophic effects in patients with possible EHS.

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