Journal of Athletic Training 2015;50(12):1240–1246
doi: 10.4085/1062-6050-51.1.05

www.natajournals.org

original research

Necessity of Removing American Football Uniforms From Humans With Hyperthermia Before Cold-Water Immersion

Kevin C. Miller, PhD, AT*; Blaine C. Long, PhD, AT*; Jeffrey Edwards, PhD†

Schools of *Rehabilitation and Medical Sciences and †Health Sciences, Central Michigan University, Mount Pleasant

Context: The National Athletic Trainers' Association and the American College of Sports Medicine have recommended removing American football uniforms from athletes with exertional heat stroke before cold-water immersion (CWI) based on the assumption that the uniform impedes rectal temperature (T_{rec}) cooling. Few experimental data exist to verify or disprove this assumption and the recommendations.

Objectives: To compare CWI durations, T_{rec} cooling rates, thermal sensation, intensity of environmental symptoms, and onset of shivering when hyperthermic participants wore football uniforms during CWI or removed the uniforms immediately before CWI.

Design: Crossover study.

Setting: Laboratory.

Patients or Other Participants: Eighteen hydrated, physically active men (age = 22 ± 2 years, height = 182.5 ± 6.1 cm, mass = 85.4 ± 13.4 kg, body fat = 11% ± 5%, body surface area = 2.1 ± 0.2 m^2) volunteered.

Intervention(s): On 2 days, participants exercised in the heat (approximately 40°C, approximately 40% relative humidity) while wearing a full American football uniform (shoes; crew socks; undergarments; shorts; game pants; undershirt; shoulder pads; jersey; helmet; and padding over the thighs, knees, hips, and tailbone [PADS]) until T_{rec} reached 39.5°C. Next, participants immersed themselves in water that was approximately 10°C while wearing either undergarments, shorts, and crew socks (NO_{pads}) or PADS without shoes until T_{rec} reached 38°C.

Main Outcome Measure(s): The CWI duration (minutes) and T_{rec} cooling rates (°C/min).

Results: Participants had similar exercise times (NO_{pads} = 40.8 ± 4.9 minutes, PADS = 43.2 ± 4.1 minutes; $t_{17} = 2.0$, $P = .10$), hypohydration levels (NO_{pads} = 1.5% ± 0.3%, PADS = 1.6% ± 0.4%; $t_{17} = 1.3$, $P = .22$), and thermal-sensation ratings (NO_{pads} = 7.2 ± 0.3, PADS = 7.1 ± 0.5; $P > .05$) before CWI. The CWI duration (median [interquartile range]; NO_{pads} = 6.0 [5.4] minutes, PADS = 7.3 [9.8] minutes; $z = 2.3$, $P = .01$) and T_{rec} cooling rates (NO_{pads} = 0.28°C/min ± 0.14°C/min, PADS = 0.21°C/min ± 0.11°C/min; $t_{17} = 2.2$, $P = .02$) differed between uniform conditions.

Conclusions: Whereas participants cooled faster in NO_{pads}, we still considered the PADS cooling rate to be acceptable (ie, >0.16°C/min). Therefore, if clinicians experience difficulty removing PADS or CWI treatment is delayed, they may immerse fully equipped hyperthermic football players in CWI and maintain acceptable T_{rec} cooling rates. Otherwise, PADS should be removed preimmersion to ensure faster body core temperature cooling.

Key Words: clothing, equipment, exertional heat stroke, rectal temperature

Key Points

- Body core temperature decreased faster when participants wore undergarments, shorts, and crew socks than when they wore the full American football uniform (PADS) without shoes during cold-water immersion (CWI).
- If CWI is delayed or clinicians have difficulty removing PADS, they can immerse hyperthermic football players in PADS and maintain acceptable core temperature cooling rates.
- The PADS should be removed before CWI if that can be done properly, easily, and within 30 minutes of athlete collapse.

American football players (AFPs) may be at higher risk of developing exertional heat stroke (EHS) in part because of the equipment-intensive uniform worn during the sport.[1] These athletes compete and often practice while wearing a full uniform consisting of shoes; crew socks; undergarments; shorts; game pants; undershirt; shoulder pads; jersey; helmet; and padding over the thighs, knees, hips, and tailbone (PADS).[2,3] The increased metabolic demand and physiologic strain of exercising while wearing PADS, combined with a decreased evaporative surface area to dissipate heat, can result in substantial heat storage[2–5] and may contribute to the development of exertional heat illness. In fact, the rate of exertional heat illness in secondary school AFPs is 11 times higher than that in all other sports combined.[6] If EHS develops and body core temperature stays above the critical threshold for cell damage (approximately 40.5°C) longer than 30 minutes, the risk of morbidity and mortality increases.[7,8] Therefore, it is paramount to develop efficient protocols for treating AFPs with hyperthermia.

The criterion standard treatment for EHS is cold-water immersion (CWI) because of its superior cooling rates (ie, >0.16°C/min)[7,9] and high survival rates when implemented shortly after the onset of symptoms.[7,10–12] However, the

Table 1. Participant Demographics (N = 18)

Characteristic	Mean ± SD
Age, y	22 ± 2
Height, cm	182.5 ± 6.1
Body mass index	25.7 ± 4.1
Sum of skinfolds, mm	38.8 ± 16.4
Body density, g/mL	1.07 ± 0.01
Body fat, %	11 ± 5
Body surface area, m²	2.1 ± 0.2

most efficient CWI protocol for treating AFPs with hyperthermia is less clear. Experts,[13] the American College of Sports Medicine (ACSM),[14] and the National Athletic Trainers' Association (NATA)[15] have recommended removing PADS before CWI if an AFP wearing PADS develops EHS. The reasoning for this recommendation was not articulated clearly, but it was not based on experimental evidence examining the influence of PADS on body core temperature cooling.[13]

Removing AFP uniforms may take several minutes[16]; whether this should be done depends on several extrinsic factors (eg, the size and temperament of the athlete, proximity to cooling tubs). Understanding the necessity of PADS removal in EHS scenarios would provide insight into the most efficient means of treating AFPs with hyperthermia. Clinically, this would provide useful guidance for the lay responder if trained medical staff are not present to quickly and skillfully remove the uniform, diagnose EHS, and implement CWI.

Miller et al[17] tested the hypothesis that participants with hyperthermia would cool slowly when wearing PADS during CWI, as implied by the ACSM[14] and NATA[15] position statements. Unexpectedly, participants cooled faster when they wore PADS than when they wore minimal clothing (ie, undergarments, shorts, crew socks). The authors speculated that this result was due to participants exercising to a thermal threshold (ie, 39.5°C) while wearing different amounts of equipment. Therefore, greater heat storage and higher skin temperatures may have occurred when they were fully equipped.[2,4,18] To test the expert recommendations,[13–15] participants would need to exercise to some hyperthermic threshold while fully equipped on 2 days, remove the equipment on 1 day, then undergo CWI. To our knowledge, no scientists have made this comparison and validated the ACSM[14] and NATA[15] recommendations. Therefore, the purpose of our study was 2-fold. First, we compared the time required to reduce the rectal temperature (T_{rec}) of individuals with hyperthermia cooled via CWI while wearing PADS or minimal clothing (undergarments, shorts, and crew socks [NO_{pads}]). However, unlike the Miller et al[17] experiment, participants exercised in PADS on both days and then removed PADS immediately before CWI on 1 day. Second, given that CWI can elicit a cold-shock response or be intolerable to conscious patients,[19] we sought to determine if wearing PADS during CWI affected thermal sensations of participants,[20] the intensity of environmental symptoms,[18] or the onset of shivering. We hypothesized that participants wearing PADS during CWI would need longer to cool from 39.5°C to 38°C, feel warmer during CWI as indicated by higher thermal-sensation ratings, report more severe environmental symptoms, and exhibit a delayed shivering response.

Table 2. Participant Descriptive Information (Mean ± SD; N = 18)

Characteristic	Condition	
	NO_{pads}[a]	PADS[b]
Pre-exercise body mass, kg	85.4 ± 13.4	85.1 ± 12.9
Postexercise body mass, kg	84.1 ± 13.3	83.7 ± 12.8
Sweat rate, L/h[c]	1.9 ± 0.5	1.9 ± 0.5

[a] For the NO_{pads} condition, participants wore undergarments, shorts, and crew socks.
[b] For the PADS condition, participants wore crew socks; undergarments; shorts; game pants; undershirt; shoulder pads; jersey; helmet; and padding over the thighs, knees, hips, and tailbone.
[c] Calculated by dividing the difference in body mass by exercise duration.

METHODS*

Participants

We recruited a convenience sample of 19 healthy, recreationally active, unacclimated men. One participant discontinued testing because of the difficulty of the exercise protocol. Eighteen participants completed the study (Tables 1 and 2). Volunteers were excluded from participating if they self-reported (1) having an injury that impaired their ability to exercise; (2) having any neurologic, respiratory, or cardiovascular disease; (3) taking any medications that may have affected fluid balance or temperature regulation (eg, diuretics); (4) having a *sedentary lifestyle*, which was defined as exercising less than 30 minutes, 3 times per week[21]; (5) having a history of heat-related illness (eg, heat exhaustion) in the 6 months preceding data collection; (6) being ill at the time of data collection; or (7) having cold allergy. All participants provided written informed consent, and the study was approved by the Central Michigan University Institutional Review Board.

Procedures

Participants reported for 2 days of testing separated by at least 72 hours. They completed their testing sessions at approximately the same time of day. We instructed them to avoid exercise, stimulants (eg, caffeine), and depressants (eg, alcohol) for 48 hours before testing; maintain a normal diet; consistently drink water the day preceding testing; and fast for 2 hours before testing. Participants were instructed to consume a similar meal the night before each testing session. Compliance was self-reported before each testing session.

Before testing, participants voided their bladders completely, and we assessed urine specific gravity (SUR-Ne refractometer; Atago USA Inc, Bellevue, WA). If urine specific gravity indicated that he was hypohydrated (ie, >1.020),[22] he was rescheduled. Euhydrated participants were weighed nude (Defender 5000; Ohaus Corp, Parsippany, NJ). Skinfold thicknesses were measured for the chest, abdomen, and thigh in triplicate and averaged per the methods of Pollack et al[23] (baseline skinfold caliper 12-1110; Fabricated Enterprises, Inc, White Plains, NY). Skinfolds were summed and used to estimate body

* Portions of the Methods section are reprinted with permission. Miller KC, Swartz EE, Long BC. Cold-water immersion for hyperthermic humans wearing American football uniforms. *J Athl Train.* 2015;50(8):792–799.

Table 3. Clothing and Equipment Worn During Cold-Water Immersion

Equipment Condition	Clothing and Equipment Worn
NO_{pads}	Undergarments,[a] shorts,[a] and crew socks[a]
PADS	Crew socks,[a] undergarments,[a] shorts,[a] game pants,[b] undershirt,[a] shoulder pads,[c] jersey,[d] helmet,[e] thigh pads,[f] knee pads,[f] hip pads,[f] and tailbone pad[f]

[a] Participants provided their own socks that extended to cover the soleus muscle, undergarments, shorts that did not extend past the knees, and undershirts with sleeves that covered the deltoid muscle group. Type and fabric composition was not controlled and likely varied among participants.
[b] Classic 3-panel pant (89% polyester, 11% spandex) with fang insert (Adidas AG).
[c] SP Mr. DZ Lineman shoulder pads (Douglas Pads & Sports, Inc, Houston, TX) in size XL.
[d] Pro-Practice 54 porthole mesh jersey (Adidas AG, Herzogenaurach, Germany) that extended to the waist.
[e] Riddell Revolution helmet with G2BD face mask (Easton-Bell Sports, Van Nuys, CA) with standard padding inside the helmet.
[f] Foam knee (model MJ-P; Adams USA Inc, Cookeville, TN), thigh, hip, and tailbone (model AHM-1/4 hip pad set; Adams USA Inc) pads. Thigh and knee pads were placed into the pouches in the game pants. The tailbone pad and hip pads were held in place by the pants belt.

density[24] and percentage of body fat.[25] Body surface area was estimated using the equation of Dubois and Dubois[26] (Table 1).

Participants donned a heart-rate monitor (Polar Electro Inc, Lake Success, NY) and inserted a rectal thermistor (YSI 4600 precision thermometer with 401 probe; Advanced Industrial Systems Inc, Prospect, KY) 20 cm past the anal sphincter to ensure appropriate thermistor depth throughout testing. Next, they put on a dry American football uniform (Table 3), entered an environmental chamber, and stood on a treadmill (model 1850; Proform Performance, Logan, UT) for 10 minutes to acclimate to the environment.[2] During this time, they were familiarized with the thermal-sensation[20] and environmental-symptoms[18] scales.

After the acclimation period, we recorded T_{rec}, thermal-sensation and environmental-symptoms scores, and environmental-chamber conditions (Kestrel Heat Stress Tracker 4400; Nielsen-Kellerman, Boothwyn, PA). Participants walked for 3 minutes at 3 mi/h (4.8 k/h) and then ran at 90% of their age-predicted maximal heart rates for 2 minutes on a standard treadmill at a 0% incline. They repeated this walking-running protocol until their T_{rec} reached 39.5°C. We continuously monitored T_{rec} to determine when it reached 39.5°C.

When T_{rec} reached 39.5°C, thermal sensation was recorded. Participants stopped exercising, stepped off the treadmill, and performed 1 of 2 actions. On the first day of testing, they removed all football equipment (we helped remove the shoulder pads) and clothing with the exception of their undergarments, shorts, and crew socks. The time to remove their clothing and equipment was measured (1.2 ± 0.2 minutes). On the second day of testing, they removed their shoes and waited next to the cold-water tub for the amount of time it took them to remove their equipment on day 1. We chose this clothing-removal order to ensure a similar lag period before CWI on both days. They entered a 1135.6-L capacity, noncirculating water tub (model 4247; Rubbermaid, Atlanta, GA) that was 160.7 cm long, 175.3 cm wide, and 63.5 cm high. They immersed themselves to the neck for the duration of cooling. All other body parts remained immersed during cooling. We started a standard stopwatch (Acu-Rite, Schaumburg, IL) the moment their feet touched the water.

A separate 401 thermistor (Advanced Industrial Systems Inc) was secured 21 cm from the bottom of the water bath to ensure the initial water-bath temperature remained approximately 10°C. We monitored water-bath temperature frequently while participants exercised and added ice if the water temperature substantially increased during testing. However, we ensured that all the ice had melted before participant entry. Participants were instructed to tell us if they started shivering. The water bath was kept in the environmental chamber to minimize transfer time and to simulate the ambient conditions that an athlete might experience while being cooled at an outdoor athletic event in the heat. The water bath was stirred each minute by tracing the skin of the athletes with a metal rod per NATA recommendations for CWI.[15] When T_{rec} was reduced to 38.75°C (half finished with cooling), participants rated their thermal sensations a third time. They remained in the water bath until T_{rec} was 38°C. We continuously monitored and recorded T_{rec} each minute. The exact time to reduce T_{rec} to 38°C was noted.

When T_{rec} reached 38°C, participants exited the water bath and rated their thermal sensation and environmental symptoms. They exited the environmental chamber, removed the football equipment (day 2) and rectal thermistor, towel dried, were weighed nude, and were excused. No fluids were given to them at any time during testing. Participants wore the same shorts, undershirt, crew socks, and shoes on both days of testing.

Statistical Analysis

Data were assessed for skewness, kurtosis, and omnibus normality to ensure normal distribution. Separate dependent *t* tests were used to determine whether differences existed between equipment conditions for urine specific gravity, environmental-chamber temperature and humidity, exercise duration, level of hypohydration postexercise, and T_{rec} cooling rates. We evaluated CWI duration using the nonparametric Wilcoxon signed-rank test because of the violation of statistical normality.

Separate repeated-measures analyses of variance were calculated to determine whether differences in thermal-sensation scores or water-bath temperatures existed between PADS and NO_{pads} over time. We summed the scores from the 16-item Environmental Symptoms Questionnaire, thereby creating a new cumulative score,[18] and analyzed the data with a repeated-measures analysis of variance. Sphericity was assessed using the Mauchly test. We made Geisser-Greenhouse adjustments to *P* values and degrees of freedom when sphericity was violated. Normality was assessed using Shapiro-Wilk tests. If we found interactions or main effects, we used Tukey-Kramer post hoc tests to identify differences between uniform conditions at each time point. The α level was set at .05. We used Number Cruncher Statistical Software (version 2007; Kaysville, UT) for all analyses.

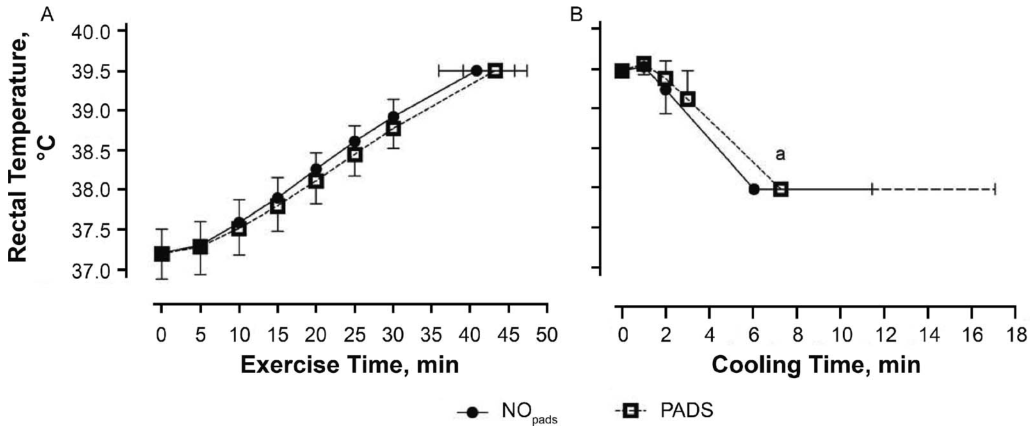

Figure 1. Rectal temperatures during A, exercise, and B, cold-water immersion (CWI) for participants wearing a full American football uniform (PADS) without shoes or minimal clothing (NO_{pads}) during CWI. Data are shown until the shortest exercise and CWI duration common to all 18 participants. All data are reported as mean ± SD with the exception of the final data point in B (median and interquartile range). The x-axis error bars indicate the SD (A) or interquartile range (B) for the final times to reach 39.5°C and 38°C, respectively. [a] Indicates PADS cooling time was longer than NO_{pads} cooling time ($P < .05$).

RESULTS

All data are reported as mean ± standard deviation with the exception of CWI duration, which is reported as median and interquartile range. Participants were well hydrated pretesting (urine specific gravity: $NO_{pads} = 1.006 \pm 0.006$, PADS = 1.003 ± 0.004; $t_{17} = 2.2$, $P = .04$). Environmental-chamber temperature ($NO_{pads} = 40°C \pm 1°C$, PADS = 40°C ± 1°C; $t_{17} = 0.7$, $P = .51$) and relative humidity ($NO_{pads} = 40\% \pm 3\%$, PADS = 39% ± 3%; $t_{17} = 1.9$, $P = .10$), pre-CWI water-bath temperatures ($NO_{pads} = 9.97°C \pm 0.03°C$, PADS = 9.97°C ± 0.06°C; $F_{1,17} = 2.3$, $P = .15$), hypohydration levels ($NO_{pads} = 1.5\% \pm 0.3\%$, PADS = 1.6% ± 0.4%; $t_{17} = 1.3$, $P = .22$), and exercise durations ($NO_{pads} = 40.8 \pm 4.9$ minutes, PADS = 43.2 ± 4.1 minutes; $t_{17} = 2.0$, $P = .10$; Figure 1) were similar on each testing day.

The duration of CWI was shorter in NO_{pads} than in PADS ($z = 2.3$, $P = .01$; Figure 1). Therefore, T_{rec} cooling rates also differed ($NO_{pads} = 0.28°C/min \pm 0.14°C/min$, PADS = 0.21°C/min ± 0.11°C/min; $t_{17} = 2.2$, $P = .02$). Thirteen of 18 participants (72%) cooled more quickly in NO_{pads}. During CWI, 12 participants shivered in NO_{pads} (shivering onset = 4.8 ± 1.2 minutes), whereas 11 participants shivered when PADS were worn (shivering onset = 5.7 ± 1.3 minutes).

We did not observe an interaction between uniform condition and time for thermal-sensation scores ($F_{2,30} = 0.9$, $P = .42$) or a difference between uniform conditions ($F_{1,17} = 0.2$, $P = .67$). However, thermal sensation changed over time ($F_{2,30} = 338.0$, $P < .001$; Figure 2). Thermal sensation pre-exercise was lower than postexercise ($P < .05$). Pre-exercise and postexercise thermal sensations were higher than the scores reported when T_{rec} was 38.75°C and post-CWI ($P < .05$). Finally, thermal-sensation scores were lower when T_{rec} was 38.75°C than post-CWI ($P < .05$).

We did not observe an interaction between uniform condition and time for environmental-symptoms scores ($F_{1,17} = 2.2$, $P = .15$; Table 4). However, we noted main effects of uniform condition and time. Participants experienced less intense environmental symptoms in PADS than in NO_{pads} ($F_{1,17} = 5.9$, $P = .03$) and reported less intense environmental symptoms pre-exercise than immediately post-CWI ($F_{1,17} = 26.6$, $P < .001$).

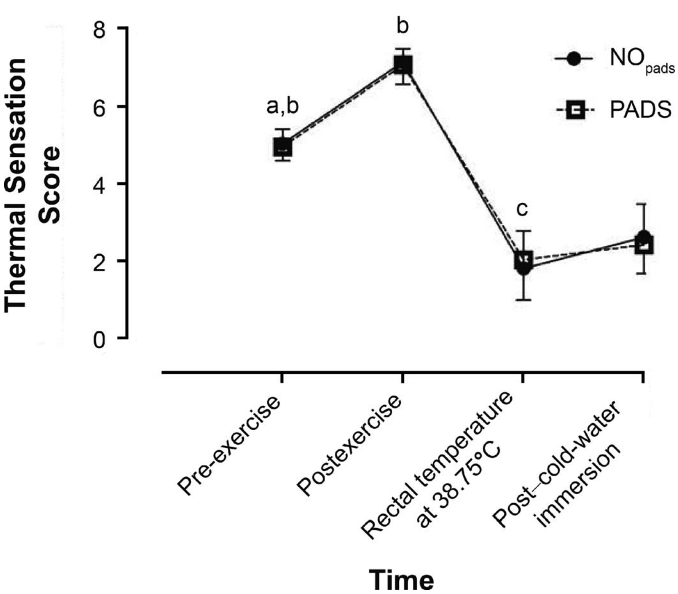

Figure 2. Participant thermal-sensation scores before, during, and after cold-water immersion while wearing a full American football uniform (PADS) or minimal clothing (NO_{pads}; mean ± SD, N = 18). Scale ratings ranged from 0 (*unbearably cold*) to 8 (*unbearably hot*). A score of 4 indicated participants were *comfortable*. [a] Indicates pre-exercise < postexercise. [b] Indicates pre-exercise and postexercise > rectal temperature at 38.75°C and post–cold-water immersion. [c] Indicates rectal temperature at 38.75°C < post–cold-water immersion ($P < .05$).

DISCUSSION

Experts,[13] the ACSM,[14] and the NATA[15] have recommended removing PADS from AFPs with EHS before CWI. However, the strength of evidence for these recommendations was low[13] and based on studies in which participants were immersed while wearing little clothing[27–29] or exercised in hot conditions while wearing football equipment.[2,4,18] To our knowledge, we are the first to provide direct evidence to support the recommendation to remove AFP equipment before CWI.[13–15]

Table 4. Environmental Symptoms Questionnaire[a] Responses (Means ± SD; N = 18)

Statement	NO_{pads}[b,c] Pre-Exercise	NO_{pads}[b,c] Post–Cold-Water Immersion	PADS[d] Pre-Exercise	PADS[d] Post–Cold-Water Immersion
1. I feel light-headed.	0 ± 0	1 ± 1	0 ± 0	1 ± 1
2. I have a headache.	0 ± 0	0 ± 0	0 ± 0	0 ± 0
3. I feel dizzy.	0 ± 0	1 ± 1	0 ± 0	1 ± 1
4. I feel faint.	0 ± 0	1 ± 1	0 ± 0	0 ± 0
5. My coordination is off.	0 ± 0	2 ± 2	0 ± 0	2 ± 1
6. It is hard to breathe.	0 ± 0	0 ± 0	0 ± 0	0 ± 0
7. I have a chest pain.	0 ± 0	0 ± 0	0 ± 0	0 ± 0
8. I have a muscle cramp.	0 ± 0	0 ± 0	0 ± 0	0 ± 0
9. I feel weak.	0 ± 0	2 ± 1	0 ± 0	1 ± 1
10. I feel sick/nauseated.	0 ± 0	0 ± 0	0 ± 0	0 ± 0
11. I feel irritable.	0 ± 0	0 ± 0	0 ± 0	0 ± 0
12. My heart is pounding.	0 ± 0	1 ± 1	0 ± 0	1 ± 1
13. I feel feverish.	0 ± 0	0 ± 0	0 ± 0	0 ± 0
14. I feel warm.	2 ± 1	1 ± 1	1 ± 1	1 ± 1
15. My vision is blurry.	0 ± 0	0 ± 0	0 ± 0	0 ± 0
16. I feel goose bumps.	0 ± 0	2 ± 2	0 ± 0	1 ± 1
Total	2 ± 1[e]	11 ± 7	1 ± 1[e]	8 ± 7

[a] The Environmental Symptoms Questionnaire is rated on a 5-point Likert scale with scores ranging from 0 (*not at all*) to 5 (*extreme*). The scores at each time point were summed to create an overall symptom score, which was analyzed statistically.
[b] Indicates main effect of uniform condition, with NO_{pads} > PADS ($P = .03$).
[c] For the NO_{pads} condition, participants wore undergarments, shorts, and crew socks.
[d] For the PADS condition, participants wore crew socks; undergarments; shorts; game pants; undershirt; shoulder pads; jersey; helmet; and padding over the thighs, knees, hips, and tailbone.
[e] Indicates main effect of time, with pre-exercise < post–cold-water immersion ($P < .001$).

The NO_{pads} T_{rec} cooling rates and immersion durations were statistically different from those for PADS because PADS insulate the body.[5] However, these differences are unlikely to be clinically meaningful for 2 reasons. First, cooling rates in both conditions were more than acceptable (ie, >0.16°C/min).[9] Second, conduction is the predominant method of heat loss during CWI, and PADS do not prevent the body's access to cold water. For example, an individual wearing PADS during CWI with a T_{rec} of 42°C would require 4 minutes of additional cooling to reach the recommended T_{rec} CWI removal temperature of 38.6°C.[30] Thus, our current data confirmed the observation of Miller et al[17] that T_{rec} cooling rates are still considered acceptable[9] when PADS are worn during CWI.

Whereas football uniforms may be removed quickly in EHS scenarios,[16] the time needed to remove PADS is based on 5 assumptions: (1) trained individuals are present to remove PADS from AFPs with EHS, (2) the individuals treating the AFPs with EHS are familiar with PADS removal, (3) the PADS are removed easily, (4) the necessary tools for uniform removal are available, and (5) AFPs are compliant with medical personnel. The clinical value of our study is in providing useful guidance when any, or all, of these assumptions are not met.

Medical professionals trained to recognize, diagnose, and treat EHS (eg, athletic trainers) may not always be present to treat AFP with EHS. Currently, fewer than 50% of US secondary schools employ full-time athletic trainers.[31] Thus, coaches, administrators, or other laypeople may be responsible for making medical decisions and initiating treatment.[32] Not having to remove football uniforms before immersing athletes with EHS would simplify the treatment process while ensuring excellent cooling rates.

Sometimes removing football uniforms is difficult (eg, unfamiliarity with equipment, mechanical failures, or unavailability of scissors). Some football equipment can be removed in approximately 3 minutes[16] but only when the removal tools are immediately available and the individuals are medical experts trained in football-uniform removal. Experts[32] have noted that many AFPs with EHS are allowed to rest next to the field of play because lay responders do not recognize EHS and initiate treatment. Failure to remove the football uniform for any of the reasons given is not a concern if lay responders initiate CWI.

The size, temperament, and level of consciousness of an athlete with EHS may also delay football-uniform removal. Most AFPs with exertional heat illness are overweight or obese (eg, linemen, linebackers).[6] Moreover, athletes with EHS often have central nervous system dysfunction that may manifest as aggression, irritability, or unconsciousness.[15] Therefore, initiating CWI may be easier and safer for individuals treating AFPs with EHS if the athletes are immersed while fully equipped.

Initiating CWI as quickly as possible is imperative, and the best prognosis occurs if CWI is initiated within 30 minutes of symptom development.[7,8] If evaluation or CWI has been delayed longer than 30 minutes, the medical professional may need to initiate treatment immediately while the AFP is fully equipped rather than spend additional minutes removing equipment. Given that the difference in CWI durations was small (approximately 1 minute), it is unlikely that wearing PADS during CWI would result in increased mortality or morbidity due to prolonged hyperthermia.

An ancillary goal of our study was to clarify the observation of Miller et al[17] of faster cooling rates when participants wore PADS during CWI versus minimal clothing. They speculated that the faster cooling of fully equipped participants was due to 1 or more of the following: (1) exercising while wearing different amounts of clothing and equipment, (2) shivering during CWI in the minimal-clothing condition, or (3) greater conductive cooling in the fully equipped condition due to PADS touching the skin.[17] Because participants cooled slower in PADS in our study despite feeling similarly hot, the observation of Miller et al[17] was likely due to skin temperatures being higher after exercise in the fully equipped condition.[2,4,18] Shivering could not explain their results, as the onset of shivering occurred 1 minute sooner in NO_{pads}. Therefore, shivering may have played only a small role in total CWI duration as a result of the relatively short CWI times.[29] Finally, it appears that wearing PADS during CWI did not convey an additional thermoregulatory advantage by providing greater conductive cooling, as illustrated by the longer CWI durations in PADS in our study.

Despite numerous lives being saved by prompt CWI,[12] researchers have criticized CWI for causing a cold-shock response; harmful, albeit transient, biochemical and physiologic changes (eg, free-radical formation, tachycardia)[33]; and discomfort to conscious patients.[19] To address whether wearing uniforms during CWI affected comfort, we asked participants about their perceptions of thermal sensation and the presence of environmental symptoms. Their thermal sensations during CWI did not differ between uniform conditions, indicating that PADS did not interfere with their perception of cold. However, PADS decreased some of the discomfort associated with CWI, as indicated by lower environmental-symptoms scores. This decreased discomfort may be due to an insulating effect of the additional clothing.[5] Whereas patient comfort should never trump optimal cooling methods,[7] our data suggested that wearing PADS decreased some CWI discomfort while still ensuring acceptable T_{rec} cooling.

If PADS are worn during CWI, medical professionals must evaluate and ensure the integrity of the cardiovascular system during EHS treatment. If PADS are left on AFPs during CWI and a life-threatening event (eg, cardiac arrest) occurs, emergency providers must remove the equipment before enacting life-saving measures. This concern could be alleviated by starting to remove equipment after the patient has been immersed.

We acknowledge the possible limitations and assumptions of our study. First, we assumed skin temperatures were similar before CWI based on the similar thermal-sensation scores reported postexercise. Thermal sensation is influenced more heavily by skin temperature than body core temperature,[20] but skin wetness plays a role in thermal sensation and should be considered when comparing our CWI thermal-sensation data with scores before and during exercise. However, several variables thought to influence the heat storage and T_{rec} of participants were similar before CWI each day: hypohydration level,[34] intensity and duration of exercise,[35] and environmental temperature and relative humidity.[36] Therefore, we do not believe the lack of skin-temperature data altered our conclusions or interpretation of the data. Second, shivering onset was self-reported and not quantified using oxygen consumption or heart rate.[29] Third, a potential order effect may have occurred in our experiment because all participants removed PADS before CWI on the first day of testing. However, the likelihood is small given that the physiologic adaptations to heat (eg, increased skin blood flow)[15] or cold (eg, shivering threshold, thermal comfort)[37] require more than 1 day of exposure. Finally, our results may not be applicable to all EHS situations. Researchers should study T_{rec} cooling rates in fully equipped female athletes and obese or overweight AFPs because sex[38] and body size can affect cooling.[39]

CONCLUSIONS

Removing AFP uniforms before CWI resulted in higher T_{rec} cooling rates and should be performed if the following conditions are met: individuals knowledgeable in equipment removal are present, removal tools (eg, scissors) are immediately available, PADS can be removed easily, and PADS interfere with the ability to fully immerse the athlete. If these considerations are not met or CWI treatment is not initiated within 30 minutes of collapse, wearing PADS during CWI with frequent stirring results in acceptable cooling rates. Finally, wearing PADS during CWI did not alter how cold participants felt during cooling but did decrease some of the negative symptoms associated with CWI and hyperthermia.

ACKNOWLEDGMENTS

We thank Michael McPike, MS; Greg McGillvary, MA, ATC; and Joseph Fox, MA, ATC, from the Athletics Department, Central Michigan University, for donating the equipment for this study.

REFERENCES

1. Kucera KL, Klossner D, Colgate B, Cantu RC; for American Football Coaches Association, National Collegiate Athletic Association, National Federation of State High School Associations, National Athletic Trainers' Association. *Annual Survey of Football Injury Research: 1931–2013*. Chapel Hill, NC: American Football Coaches Association, National Collegiate Athletic Association, National Federation of State High School Associations, National Athletic Trainers' Association; 2014:1–31. http://nccsir.unc.edu/files/2014/06/Annual-Football-2013-Fatalities-Final.pdf. Accessed October 7, 2015.
2. Armstrong L, Johnson E, Casa D, et al. The American football uniform: uncompensable heat stress and hyperthermic exhaustion. *J Athl Train*. 2010;45(2):117–127.
3. Kulka TJ, Kenney WL. Heat balance limits in football uniforms: how different uniform ensembles alter the equation. *Physician Sportsmed*. 2002;30(7):29–39.
4. Mathews D, Fox E, Tanzi D. Physiological responses during exercise and recovery in a football uniform. *J Appl Physiol*. 1969;26(5):611–615.
5. McCullough E, Kenney W. Thermal insulation and evaporative resistance of football uniforms. *Med Sci Sports Exerc*. 2003;35(5):832–837.
6. Kerr Z, Casa D, Marshall S, Comstock R. Epidemiology of exertional heat illness among U.S. high school athletes. *Am J Prev Med*. 2013;44(1):8–14.
7. Casa D, McDermott B, Lee E, Yeargin S, Armstrong L, Maresh C. Cold water immersion: the gold standard for exertional heatstroke treatment. *Exerc Sport Sci Rev*. 2007;35(3):141–149.
8. Hubbard R, Bowers W, Matthew W, et al. Rat model of acute heatstroke mortality. *J Appl Physiol Respir Environ Exerc Physiol*. 1977;42(6):809–816.
9. McDermott B, Casa D, Ganio M, et al. Acute whole-body cooling for exercise-induced hyperthermia: a systematic review. *J Athl Train*. 2009;44(1):84–93.

10. Vicario S, Okabajue R, Haltom T. Rapid cooling in classic heatstroke: effect on mortality rates. *Am J Emerg Med*. 1986;4(5): 394–398.
11. Costrini A. Emergency treatment of exertional heatstroke and comparison of whole-body cooling techniques. *Med Sci Sports Exerc*. 1990;22(1):15–18.
12. DeMartini J, Casa D, Stearns R, et al. Effectiveness of cold water immersion in the treatment of exertional heat stroke at the Falmouth Road Race. *Med Sci Sports Exerc*. 2015;47(2):240–245.
13. Bergeron M, McKeag D, Casa D, et al. Youth football: heat stress and injury risk. *Med Sci Sports Exerc*. 2005;37(8):1421–1430.
14. Armstrong L, Casa D, Millard-Stafford M, Moran D, Pyne S, Roberts W. American College of Sports Medicine position stand: exertional heat illness during training and competition. *Med Sci Sports Exerc*. 2007;39(3):556–572.
15. Binkley H, Beckett J, Casa D, Kleiner D, Plummer P. National Athletic Trainers' Association position statement: exertional heat illnesses. *J Athl Train*. 2002;37(3):329–343.
16. Endres B, Decoster L, Swartz E. Football equipment removal in an exertional heat stroke scenario: time and difficulty. *Athl Train Sports Health Care*. 2014;6(5):213–219.
17. Miller K, Swartz E, Long B. Cold-water immersion for hyperthermic humans wearing American football uniforms. *J Athl Train*. 2015; 50(8):792–799.
18. Johnson E, Ganio M, Lee E, et al. Perceptual responses while wearing an American football uniform in the heat. *J Athl Train*. 2010; 45(2):107–116.
19. Smith J. Cooling methods used in the treatment of exertional heat illness. *Br J Sports Med*. 2005;39(8):503–507.
20. Young J, Sawka M, Epstein Y, Decristofano B, Pandolf K. Cooling different body surfaces during upper and lower body exercise. *J Appl Physiol (1985)*. 1987;63(3):1218–1223.
21. Thompson W, Gordon N, Pescatello L. Preparticipation health screening and risk stratification. In: Thompson W, Gordon N, Pescatello L, eds. *ACSM's Guidelines for Exercise Testing and Prescription*. 8th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2010:18–39.
22. Sawka M, Burke L, Eichner E, Maughan R, Montain S, Stachenfeld N. American College of Sports Medicine position stand: exercise and fluid replacement. *Med Sci Sports Exerc*. 2007;39(2):377–390.
23. Pollack M, Schmidt D, Jackson A. Measurement of cardio-respiratory fitness and body composition in the clinical setting. *Compr Ther*. 1980;6(9):12–27.
24. Jackson A, Pollock M. Generalized equations for predicting body density of men. *Br J Nutr*. 1978;40(3):497–504.
25. Siri W. Body composition from fluid spaces and density: analysis of methods. In: Brozek J, Henschel A, eds. *Techniques for Measuring Body Composition*. Washington, DC: National Academies Press; 1961:223–244.
26. DuBois D, DuBois E. A formula to estimate the approximate surface area if height and weight be known. 1916. *Nutrition*. 1989;5(5):303–311.
27. Armstrong L, Crago A, Adams R, Roberts W, Maresh C. Whole-body cooling of hyperthermic runners: comparison of two field therapies. *Am J Emerg Med*. 1996;14(4):355–358.
28. Clements J, Casa D, Knight J, et al. Ice-water immersion and cold-water immersion provide similar cooling rates in runners with exercise-induced hyperthermia. *J Athl Train*. 2002;37(2):146–150.
29. Proulx C, Ducharme M, Kenny G. Effect of water temperature on cooling efficiency during hyperthermia in humans. *J Appl Physiol (1985)*. 2003;94(4):1317–1323.
30. Gagnon D, Lemire B, Casa D, Kenny G. Cold-water immersion and the treatment of hyperthermia: using 38.6°C as a safe rectal temperature cooling limit. *J Athl Train*. 2010;45(5):439–444.
31. Pryor R, Casa D, Vandermark L, et al. Athletic training services in public secondary schools: a benchmark study. *J Athl Train*. 2015; 50(2):156–162.
32. Casa D, Armstrong L, Kenny G, O'Connor F, Huggins R. Exertional heat stroke: new concepts regarding cause and care. *Curr Sports Med Rep*. 2012;11(3):115–123.
33. Bleakley C, Davison G. What is the biochemical and physiological rationale for using cold-water immersion in sports recovery? A systematic review. *Br J Sports Med*. 2010;44(3):179–187.
34. Montain S, Coyle E. Influence of graded dehydration on hyperthermia and cardiovascular drift during exercise. *J Appl Physiol (1985)*. 1992;73(4):1340–1350.
35. Rav-Acha M, Hadad E, Epstein Y, Heled Y, Moran D. Fatal exertional heat stroke: a case series. *Am J Med Sci*. 2004;328(2):84–87.
36. DeMartini J, Casa D, Belval L, et al. Environmental conditions and the occurrence of exertional heat illnesses and exertional heat stroke at the Falmouth Road Race. *J Athl Train*. 2014;49(4):478–485.
37. Golden F, Tipton M. Human adaptation to repeated cold immersions. *J Physiol*. 1988;396:349–363.
38. Lemire B, Gagnon D, Jay O, Kenny G. Differences between sexes in rectal cooling rates after exercise-induced hyperthermia. *Med Sci Sports Exerc*. 2009;41(8):1633–1639.
39. Friesen B, Carter M, Poirier M, Kenny G. Water immersion in the treatment of exertional hyperthermia: physical determinants. *Med Sci Sports Exerc*. 2014;46(9):1727–1735.

Address correspondence to Kevin C. Miller, PhD, AT, School of Rehabilitation and Medical Sciences, Central Michigan University, 1208 Health Professions Building, Mount Pleasant, MI 48859. Address e-mail to mille5k@cmich.edu.