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Physiological and Perceived Effects of Forearm or Head Cooling During Simulated Firefighting Activity and Rehabilitation

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Context: Cooling devices aim to protect firefighters by attenuating a rise in body temperature. Devices for head cooling (HC) while firefighting and forearm cooling (FC) during rehabilitation (RHB) intervals are commonly marketed, but research regarding their efficacy is limited.

Objective: To investigate the physiological and perceived effects of HC and FC during firefighting drills and RHB.

Design: Randomized controlled clinical trial.

Setting: Firefighter training center.

Patients or Other Participants: Twenty-seven male career firefighters (age = 39 ± 7 years; height = 169 ± 7 cm; weight = 95.4 ± 16.8 kg).

Intervention(s): Firefighters were randomly assigned to 1 condition: HC (n = 9), in which participants completed drills wearing a cold gel pack inside their helmet; FC (n = 8), in which participants sat on a collapsible chair with water-immersion arm troughs during RHB; or control (n = 10), in which participants used no cooling devices. Firefighters completed four 15-minute drills (D1–D4) wearing full bunker gear and breathing apparatus. Participants had a 15-min RHB after D2 (RHB1) and D4 (RHB2).

Main Outcome Measure(s): Change (Δ) in gastrointestinal temperature (T_{GI}), heart rate (HR), physiological strain index, and perceived thermal sensation.

Results: The T_{GI} increased similarly in the HC and control groups, respectively (D1: 0.57°C ± 0.41°C, 0.73°C ± 0.30°C; D2: 0.92°C ± 0.28°C, 0.85°C ± 0.27°C; D3: –0.37°C ± 0.34°C, –0.01°C ± 0.72°C; D4: 0.25°C ± 0.42°C, 0.57°C ± 0.26°C; $P > .05$). The ΔHR, Δ physiological strain index, and Δ thermal sensation were similar between the HC and control groups during drills ($P > .05$). The FC group demonstrated a decreased T_{GI} compared with the control group after RHB1 (–1.61°C ± 0.35°C versus –0.23°C ± 0.34°C; $P < .001$) and RHB2 (–1.40°C ± 0.38°C versus –0.38°C ± 0.24°C; $P < .001$). The physiological strain index score decreased in the FC group compared with the control group after RHB1 (–7.9 ± 1.3 versus –2.6 ± 1.7; $P < .001$) and RHB2 (–7.9 ± 1.6 versus –3.6 ± 1.1; $P < .001$), but no differences between groups were demonstrated for ΔHR or Δ thermal sensation ($P > .05$).

Conclusions: The HC did not attenuate rises in physiological or perceptual variables during firefighting drills. The FC effectively reduced T_{GI} and the physiological strain index score but not HR or thermal sensation during RHB. Clinicians and firefighters should not recommend the use of HC during firefighting but can consider using FC during RHB intervals in the field.

Key Words: body temperature, thermal strain, hydration status

Key Points

- The head-cooling device failed to attenuate the rise in gastrointestinal temperature during firefighting activity and should not be recommended.
- Forearm cooling could not attenuate the rise in gastrointestinal temperature during firefighting activity.
- Forearm cooling can be recommended for firefighters actively engaged in the field to aid return of gastrointestinal temperature and physiological strain index score to baseline values.

Firefighters tolerate a high level of physical demands, including stair climbing, victim search and rescue, and moving heavy equipment.[1–3] These metabolically challenging demands require a mixture of sustained aerobic and maximal anaerobic capabilities, depending on the dynamics of the emergency (eg, building fire, car extrication, forced entry). When combined with extrinsic factors of ambient temperatures as high as 100°C to 278°C inside live fires, flame radiant heat,[1,4] and heavy protective clothing with self-contained breathing apparatus (SCBA),[5] rises in core body temperatures are inevitable.[2,6,7] As firefighters combat active fires, physiological and thermoregulatory strain competitively increase due to elevations in heart rate (HR)[2,3,6] and reductions in cardiac output.[2] As physiological strain intensifies, firefighters also perceive that they feel hotter and are working harder.[8]

Organ morbidity and mortality rates are directly proportional to rises in body temperature beyond the critical threshold (ie, hyperthermia > 40°C).[9,10] Poor hydration status, preexisting illness, and sleep deprivation in conjunction with contributing occupational factors may also promote the development of exertional heat stroke.[9,11] Exertional heat illnesses and corresponding fatalities[12,13] are reported yearly in firefighters while on duty. To protect firefighters from adverse events such as exertional hyperthermia, exhaustion, dehydration, and burns, several safety procedures exist, including work-monitoring programs and uniform modifications.[14–16] The National Fire Protection Agency standard #1584, *Standard on the Rehabilitation Process for Members During Emergency Operations and Training Exercises*,[15] specifically recommends rehabilitation intervals during sustained firefighting activity depending on the number of minutes the firefighter is actively engaged with the fire. Accessory cooling devices used in the field during work or rehabilitation intervals are commonly marketed to fire departments as an additional method of avoiding exertional hyperthermia. Cooling vests,[17–21] fans,[18] and water misters[22] have been investigated as ways of protecting firefighters from a dangerous rise in core body temperature with an array of favorable to ineffective results.

Head cooling is 1 method that has been studied in diverse settings and during various activities.[23–25] However, firefighters and the unique physical demands they face have not been investigated, and whether head cooling in firefighters attenuates a rise in body temperature is unknown. Forearm cold-water immersion has been explored in firefighters.[17,18,22,26–28] Yet the majority of studies were confined to laboratory exercise protocols, making it difficult to generalize results to the field setting and apply them to developing recommendations for firefighter safety. The protocols used various water temperatures between 10°C and 20°C for forearm immersion with contrasting meaningful and insignificant results.[17,18,22,26–28] Previous research examining persons with hyperthermia in laboratory and field settings have indicated that whole-body ice-water (<5°C) immersion produces the fastest cooling rates with successful body temperature reductions.[29,30] Nevertheless, we do not yet know if applying ice-water to the forearms alone could successfully decrease core temperature in firefighters with mild hyperthermia while conducting simulated firefighting activities.

Therefore, the primary purpose of this investigation was to evaluate the efficacy of 2 commercially available field cooling devices in firefighters for attenuating the rise in gastrointestinal temperature (T_{GI}) during drills (head cooling) or reducing T_{GI} during rehabilitation (forearm cooling). The secondary purpose was to evaluate additional physiological (HR and physiological strain index) and perceptual (perceived thermal sensation) responses to these field cooling devices.

METHODS

We used a randomized controlled clinical trial to investigate the efficacy of field cooling devices during simulated firefighting activity (FFA) or rehabilitation (RHB). The research setting was the district's firefighter training center. The university's institutional review board approved the experimental protocol, and each participant signed an informed consent form indicating that he understood the study's procedures and risks. All participants had the results of a medical physical examination on file with the fire department indicating that they were fit for work and medically cleared to use an SCBA without accommodation or restriction. Having a scheduled magnetic resonance imaging procedure, a gastrointestinal illness or condition, or difficulty swallowing large pills were exclusionary criteria for the use of the telemetric temperature sensors.

A total of 38 career firefighters from 8 stations volunteered to participate in the study. Eleven volunteers were excluded from data analyses because they were unable to complete all 4 FFA drills or their ingestible thermistor failed to travel far enough into the intestine for accurate T_{GI} measurement. This was identified when baseline T_{GI} was too low (>36.7°C) for the person to be considered normothermic. All participants who were unable to complete FFA drills volitionally removed themselves due to physical fatigue. Data from the remaining 27 men were used for analysis of all variables.

Environmental Conditions, Demographics, and Hydration Characteristics

Ambient temperature and humidity were measured at least once each hour using a heat stress monitor (model Metrosonics HS-32; Quest Technologies, Oconomowoc, WI). The device was positioned outside in a location central to the 4 FFA drills. The participant's self-reported age was recorded; height was measured to the nearest centimeter using a standard tape measure fixed to a wall. Body mass was measured to the nearest 0.1 kg (model BWB-800; Tanita Corporation of America, Inc, Arlington Heights, IL) with firefighters wearing only the shorts or pants they would be wearing under their personal turnout gear during the FFA drills. Aerobic capacity was estimated from recovery HR using a submaximal step test on a day before data collection.[31]

Firefighters provided urine samples for the measurement of pre-FFA and post-FFA urine specific gravity using a handheld clinical refractometer (model A300CL; ATAGO U.S.A., Inc, Bellevue, WA). The refractometer was calibrated according to the manufacturer's guidelines. Fluid consumed was determined by using a standard 1-L bottle for each firefighter and recording added or remaining fluids throughout the FFA. Total sweat loss was determined with the following formula: ([Pre-FFA body mass − Post-FFA body mass] + Fluid consumed − Urine output).

Main Outcome Measures

The T_{GI} was measured by ingestible thermistor (model HT150002; HQ Inc, Palmetto, FL), which transmitted a signal to a handheld data receiver (model HT150016; HQ Inc). An ingestible thermistor was distributed to each firefighter after arrival at the station for his shift and was ingested 5 hours before the scheduled arrival time at the training facility. The HR straps (model T31-noncoded; Polar Electro Inc, New Hyde Park, NY) worn at the participant's xiphoid process level sent a signal to the corresponding watch worn by a researcher, who recorded T_{GI} and HR at baseline and at the end of each 15-minute FFA drill and RHB interval. Data points represented a single time point. Absolute T_{GI} was the average of 2 measurements taken simultaneously. Measurements of T_{GI} and HR took approximately 5 seconds to acquire from the

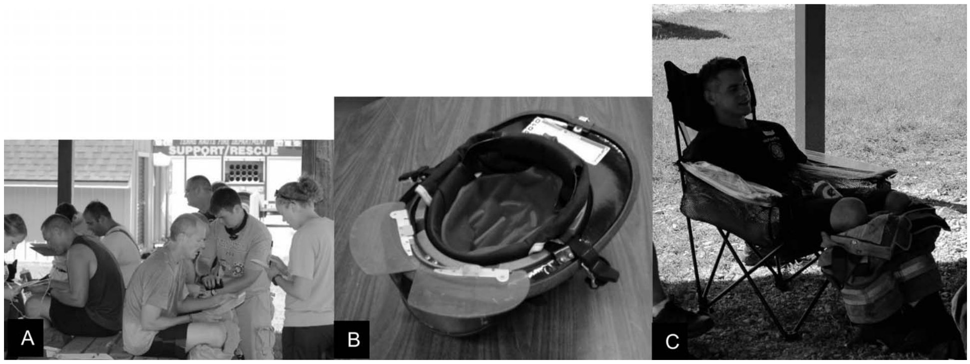

Figure 1. Firefighting activity and rehabilitation sequence. A. Control. B, Head cooling. C, Forearm cooling.

measuring devices. Changes in all variables during FFA drills were calculated by subtracting the values at the end of 1 period from the values at the end of the previous period (ie, end drill 1 – baseline [ΔD1], end drill 2 – end drill 1 [ΔD2], end drill 3 – end RHB1 [ΔD3], end drill 4 – end drill 3 [ΔD4]). Changes in all variables during RHB were calculated by subtracting the values at the end of RHB from the values at the end of the previous drill (ie, end of drill 2 – end of RHB1 [ΔR1]; end of drill 4 – end of RHB2 [ΔR2]). Physiological strain index scores were calculated at the end of each drill and RHB interval using the following formula: physiological strain index $= 5\,(T_{GIt} - T_{GI0}) \cdot (39.5 - T_{GI0})^{-1} + 5\,(HR_t - HR_0) \cdot (180 - HR_0)^{-1}$, where T_{GIt} and HR_t were simultaneous measurements taken at any time during FFA and T_{GI0} and HR_0 were baseline measurements. A score of 1 represents *no/little heat strain*, 5 represents *moderate strain*, and 9 represents *very high heat strain*.[32]

Perceived Thermal Sensation

Firefighters were shown a visual scale numbered from 0 to 8 (0 = *unbearably cold* and 8 = *unbearably hot*). The firefighters indicated how cold or hot they felt at the time based on the scale descriptions.[33] This value was recorded at the end of every FFA drill and RHB.

Experimental Protocol

Conditions. Firefighters were randomly assigned to the control (CON; n = 10), head-cooling (HC; n = 9), or forearm-cooling (FC; n = 8) group when they arrived at the training facility. The control group (Figure 1A) did not receive any accessory cooling during FFA drills or RHB. Those assigned to HC inserted a gel pack (model GX; GelCool Systems Inc, Nashville, TN) that had just been removed from the freezer into the top of their helmet. The gel pack was circular and had compartments intended to conform to the shape of the head and helmet (Figure 1B). Some firefighters adjusted the straps inside the helmet to accommodate the size of the gel pack, whereas others placed it directly behind the straps. The microfiber side was placed facing the firefighter's head and the front of the helmet per the manufacturer's instructions.

Forearm cooling occurred in a collapsible chair (Kore Kooler Rehab Chair; DQE, Inc, Fishers, IN) with water-immersion troughs built into the arm rests (Figure 1C). Firefighters fully immersed their forearms from the humeral epicondyles to the distal metacarpals in 5°C water. Water temperature was measured before and during RHB and kept at a consistent temperature by adding ice. Firefighters remained seated with their forearms immersed for the full 15-minute RHB time frame. After RHB was complete, the FC group toweled off before donning bunker coats again. All groups rested in the shade during RHB.

Firefighting Activity Drills. Participants were scheduled by the district's training officer based on convenience depending on company and shift. Two data-collection sessions were held each day in the morning (AM) and afternoon (PM) for 3 consecutive days. Participants within each group completed the training as follows: control group (AM: n = 6, PM: n = 4), HC group (AM: n = 6, PM: n = 3), and FC group (AM: n = 4, PM: n = 4). Firefighters donned an HR strap, bunker pants with suspenders, steel-toed boots, and bunker coats before baseline HR, T_{GI}, and thermal sensation were recorded soon after arrival. Firefighters put on their remaining turnout gear, including Nomex (DuPont USA, Wilmington, DE) hoods, gloves, helmets, SCBA with a mask (Dräger, Inc, Houston, TX), and a 20-minute 450-psi air bottle (23.3 ± 1.4 kg) immediately before the drills.

Firefighters were randomly assigned to their starting FFA drill. The modified combat-challenge protocol[34] consisted of four 15-minute FFA drills: obstacle course, high-rise drill, 2-story search-and-rescue drill, and car extrication (Figure 2). During the outdoor obstacle course, firefighters crawled on their hands and knees while following a hose (12.7 kg) on the ground over and through various props and then used an armpit drag to move an International Association of Fire Fighters Rescue Randy (75 kg; Simulaids Inc, Saugerties, NY). For the high-rise drill, the firefighters carried either a hose or an appliance kit (on alternating trips) up 4 flights of stairs to the top of a smoke-filled tower and the pipe where the hose would be attached and then descended the stairs to the bottom of the tower. To simulate a search and rescue, firefighters crawled on their hands and knees through a smoke-filled, 2-story residence while following a hose and crawling through props and up and down stairs. For the car-extrication drill, firefighters worked outdoors in the sun without wearing SCBA. They were allowed to self-pace completion of the task during each drill but kept repeating the task for the entire 15-minute time frame.

Firefighters completed the first FFA drill and then reported to the exchange area to replace their air tanks. Those assigned to the HC group also replaced their head-cooling gel pack with a fresh gel pack from the freezer at

Figure 2. Firefighting activity drills. A, Obstacle course. B, High-rise drill carry. C, Search and rescue (outdoor portion). D, Car extrication.

this time. After the exchange, the firefighters rotated to the next drill in the sequence. They then reported to the RHB area, where all groups rested for 15 minutes by sitting in the shade; removed their SCBA, helmet, hood, gloves, and jacket; and lowered their trousers. The RHB did not begin until all participants were seated on benches (HC and CON groups) or chairs (FC). This RHB procedure is consistent with national recommendations.[15] Firefighters drank tepid water ad libitum. At the end of RHB, firefighters redressed and completed the drill-exchange-drill-rehabilitation sequence a second time.

Statistical Analysis

Descriptive statistics were calculated for each variable (mean $\pm$ standard deviation). One-way analysis of variance was calculated to evaluate whether group differences existed in demographic and hydration characteristics. Planned comparisons were used to evaluate each aim specifically because the treatments did not occur at the same time during the protocol (ie, HC was administered during FFA drills and FC was administered during RHB). Multiple comparisons within the same family were corrected with a Bonferroni adjustment. Significance was set a priori at $P < .05$. An a priori power calculation was performed using G*Power (version 3.1; Heinrich Heine University, Dusseldorf, Germany) to estimate sample size based on previous literature.[7,35] After 15 and 30 minutes of FFA, T_{GI} increases of about 0.7°C and 1.3°C, respectively, with standard deviations of 0.2°C were expected. Thresholds for clinical meaningfulness were a mean increase of only 0.3°C in T_{GI} for the HC group and a 1.0°C difference in the FC group. With $\alpha = .05$ and power $= 0.8$, the projected sample size needed was approximately 6 participants per group for the simplest between-groups comparisons. All statistical analyses were completed using SPSS (version 21; IBM Corp, Armonk, NY).

RESULTS

Participant, Environmental, and Drill Characteristics

Demographics, baseline physiological status, baseline hydration status, and hydration variables did not differ between groups ($P > .05$; Table 1). Environmental conditions were hot with moderate humidity (33.1°C $\pm$ 1.4°C, 27% $\pm$ 3% relative humidity). Ambient temperature and relative humidity were not different across the 6 data-collection sessions ($P > .05$). Ambient temperatures were 29.6°C to 30.1°C, 28.7°C to 29.7°C, and 30.7°C to 32.3°C on the 3 days of data collection. Firefighters' maximum T_{GI} ranged from 38.35°C to 40.22°C, and HR reached 174 $\pm$ 11 beats per minute with firefighters working at an average of 88% $\pm$ 7% of their age-adjusted maximum HRs during drills. The physiological strain index score averaged 7 $\pm$ 1 units among firefighters when performing drills.

Efficacy of HC During Drills

The rise (ie, Δ) in T_{GI} was not different between groups during D1 or D2 ($P > .05$; Table 2); however, T_{GI} was different between D3 and D4. The change in T_{GI} was greater in the FC group compared with the CON group at D3 and D4 ($P = .006$) given that T_{GI} was reduced during RHB1 while T_{GI} remained elevated in the CON and HC groups. Absolute T_{GI} was not different between groups at baseline, D1, D2, D3, or D4 ($P > .007$ after correction for multiple comparisons; Table 3). Head cooling did not attenuate the rise in HR, physiological strain index scores, or thermal sensation compared with the CON group during any drills ($P > .05$; Table 2). The FC group demonstrated greater rises in HR and physiological strain index score after D3 compared with the control and HC groups ($P < .008$; Table 2). Measures in the FC group returned to near baseline after RHB, resulting in an increased capacity to store heat and thus a greater rise in these measures when firefighters returned to the drills.

Table 1. Firefighter Demographic, Physiological, and Hydration Characteristics

Characteristic	Group (Mean ± SD) Control	Head Cooling	Forearm Cooling	*F* Value	*P* Value[a]
Age, y	39 ± 9	41 ± 6	37 ± 6	0.8	.479
Height, cm	166 ± 8	169 ± 6	171 ± 8	1.1	.359
Weight, kg	88.6 ± 12.8	95.5 ± 15.5	103.8 ± 20.3	2.0	.164
Weight of gear, kg	23.51 ± 1.62	22.99 ± 1.14	23.43 ± 1.48	0.3	.710
Estimated $\dot{V}O_2$, mL•kg^{-1}•min^{-1}	51 ± 8	53 ± 7	50 ± 5	0.3	.755
Pre-FFA					
Perceived thermal sensation	4 ± 1	5 ± 1	5 ± 1	1.6	.233
Gastrointestinal temperature, °C	37.61 ± 0.38	37.71 ± 0.29	37.88 ± 0.17	1.9	.177
Heart rate, bpm	119 ± 29	110 ± 19	122 ± 13	0.7	.511
Urine specific gravity	1.015 ± 0.006	1.016 ± 0.007	1.016 ± 0.010	0.1	.919
Post-FFA urine specific gravity	1.018 ± 0.009	1.023 ± 0.005	1.017 ± 0.008	2.0	.160
Total sweat loss, L	2.36 ± 0.75	2.72 ± 0.79	1.98 ± 0.68	2.1	.142
Total fluid consumed, L	1.48 ± 0.55	1.93 ± 1.07	1.65 ± 0.88	0.7	.515

Abbreviations: bpm, beats per minute; FFA, firefighting activity.

[a] The groups did not differ ($P > .05$).

Efficacy of FC During Rehabilitation

Change in T_{GI} in the FC group decreased by the end of each RHB compared with the CON and HC groups ($P < .001$; Table 4). However, the change in T_{GI} was not different ($P > .05$) between groups from baseline to the end of the preceding drill (ie, drill 4; control = 1.51°C ± 0.6°C, HC = 1.52°C ± 0.5°C, FC = 1.45°C ± 0.4°C). Absolute T_{GI} was not different between groups at baseline, D1, D2, D3, or D4 ($P > .05$; Table 3) but was lower than the CON ($P = .021$, $P < .001$) and HC ($P < .001$, $P = .001$) groups by the end of RHB1 and RHB2, respectively (Table 3). This indicates that each group entered RHB1 and RHB2 with a similar absolute T_{GI}. Forearm cooling reduced the physiological strain index score after both RHB1 and RHB2 compared with the other groups ($P < .001$), but no differences between groups were demonstrated for HR or thermal sensation ($P > .05$; Table 4).

DISCUSSION

Previous researchers have investigated various cooling techniques marketed to firefighters but few have examined devices in the field setting. Our aims were to evaluate the

Table 2. Changes in Physiological and Perceptual Variables After Each Firefighting Activity Drill

ΔD[a]	Group (Mean ± SD) Control	Head Cooling	Forearm Cooling	*F* Value	*P* Value
Gastrointestinal temperature, °C					
D1	0.57 ± 0.41	0.73 ± 0.30	0.77 ± 0.15	1.1	.361
D2	0.92 ± 0.28	0.85 ± 0.27	0.75 ± 0.36	0.6	.532
D3	–0.37 ± 0.34	–0.01 ± 0.72	0.44 ± 0.19[b]	6.4	.006
D4	0.25 ± 0.42	0.57 ± 0.26	0.85 ± 0.37[b]	6.3	.006
Heart rate, beats per minute					
D1	43 ± 18	46 ± 26	41 ± 9	0.1	.900
D2	–4 ± 27	5 ± 32	0 ± 17	0.2	.783
D3	31 ± 13	40 ± 19	59 ± 20[b]	6.1	.007
D4	7 ± 15	2 ± 15	–6 ± 14	1.8	.188
Physiological strain index score					
D1	6.1 ± 1.4	6.2 ± 1.5	6.8 ± 0.9	0.6	.532
D2	1.8 ± 1.5	2.4 ± 1.7	2.1 ± 1.1	0.3	.729
D3	1.0 ± 1.0	2.0 ± 2.9	4.8 ± 1.1[c]	9.5	.001
D4	0.8 ± 1.5	1.6 ± 1.4	1.9 ± 1.1	1.8	.192
Perceived thermal sensation					
D1	2 ± 1	1 ± 1	2 ± 1	1.8	.195
D2	1 ± 1	0 ± 1	1 ± 1	0.1	.934
D3	2 ± 1	2 ± 1	2 ± 1	0.4	.677
D4	1 ± 1	0 ± 1	1 ± 1	0.8	.441

[a] D1, change in variable from the end of drill 1 to baseline; D2, change in variable from end of drill 2 to end of drill 1; D3, change in variable from end of drill 3 to end of rehabilitation 1; D4, change in variable from end of drill 4 to end of drill 3. A 1-way analysis of variance to test for differences between groups was used for each ΔD with post hoc group comparisons, if necessary, to determine whether head cooling attenuated the rise of any variable during the drills.

[b] Forearm cooling increased more than control. Head cooling and control were not different.

[c] Forearm cooling increased more than head cooling and control. Head cooling and control were not different.

Table 3. Absolute Gastrointestinal Temperature Values After Each Firefighting Activity Drill and Rehabilitation[a]

Time	Group (Mean ± SD)			*F* Value	*P* Value
	Control	Head Cooling	Forearm Cooling		
Baseline	37.23 ± 0.33	37.50 ± 0.40	37.63 ± 0.23	3.5	.046
Gastrointestinal temperature, °C					
D1	38.17 ± 0.44	38.44 ± 0.41	38.65 ± 0.22	3.6	.043
D2	39.08 ± 0.51	39.28 ± 0.46	39.40 ± 0.46	0.9	.397
Rehabilitation 1	38.86 ± 0.43	38.47 ± 0.67	37.79 ± 0.21[b]	10.9	<.001
D3	38.49 ± 0.44	38.46 ± 0.33	38.23 ± 0.27	1.3	.293
D4	38.74 ± 0.48	39.02 ± 0.19	39.08 ± 0.43	2.0	.154
Rehabilitation 2	38.36 ± 0.46	38.62 ± 0.28	37.68 ± 0.28[b]	15.5	<.001

[a] D1, end of drill 1 to baseline; D2, end of drill 2; D3, end of drill 3; D4, end of drill 4; RHB1, end of rehabilitation 1; RHB2, end of rehabilitation 2. A 1-way analysis of variance was used to test for differences between groups for each drill and rehabilitation interval with Bonferroni adjustments and post hoc group comparisons as necessary.

[b] Forearm cooling reduced gastrointestinal temperature more than the control or head-cooling condition.

efficacy of 2 field cooling devices in changing physiological and perceptual variables during firefighting activity or rehabilitation.

Participant, Environmental, and Drill Characteristics

The descriptive variables did not differ between groups or data-collection sessions. Based on these results, we can attribute any reported differences in dependent variables to the experimental conditions. The FFA drills in the present study were strenuous and mimicked the demands firefighters experience while actively engaged in a live fire or rescue effort. The descriptive values are similar to or greater than those presented by previous researchers who examined firefighters' physiological variables in the field[2] and laboratory[3,6,7,19] settings. Physiological strain index scores were moderate to high during performance of the FFA drills.[8,32]

Efficacy of HC During Drills

Our first research aim was to evaluate if HC attenuated physiological and perceptual variables during FFA drills. We found that HC was ineffective in attenuating all outcome measures (T_{GI}, HR, physiological strain index score, or thermal sensation) compared with the control group. The failure of the HC device to reduce these variables may be explained by the device's limited ability to maintain its original temperature and by the size and type of surface area.

Although participants used the gel packs for only 15 minutes, T_{GI} was unaffected. Basic physiology explains that the greater the temperature gradient, the greater the heat transfer. Wickwire et al[25] noted that a helmet-cooling pad equalized within 30 minutes, so we speculate that the temperature gradient gradually decreased during our FFA. As the temperature gradient decreased, so did conductive heat dissipation. Furthermore, some firefighters reported that the gel pack fit awkwardly inside the helmet, even with strap adjustments. The one-size-fits-all device contacted only the most superior portion of the cranium. The ability to effectively transfer heat away from the head may have been restricted by this small surface area of contact between the gel pack and the head. The microfiber material of the gel pack and the firefighter's hair may have also moderated the contact and cooling capacity. Preliminary modality re-

Table 4. Change in Physiological and Perceptual Variables After RHB[a]

Time	Group (Mean ± SD)			*F* Value	*P* Value
	Control	Head Cooling	Forearm Cooling		
Gastrointestinal temperature, °C					
ΔRHB1	–0.23 ± 0.34	–0.81 ± 0.58	–1.61 ± 0.35[b]	22.1	<.001
ΔRHB2	–0.38 ± 0.24	–0.40 ± 0.20	–1.40 ± 0.38[b]	37.4	<.001
Heart rate, bpm					
ΔRHB1	–36 ± 24	–46 ± 19	–57 ± 21	2.1	.145
ΔRHB2	–47 ± 18	–52 ± 18	–66 ± 9	3.1	.066
Physiological strain index score					
ΔRHB1	–2.6 ± 1.7	–4.6 ± 2.0	–7.9 ± 1.3	21.8	<.001
ΔRHB2	–3.6 ± 1.1	–3.8 ± 1.0	–7.9 ± 1.6	31.0	<.001
Perceived thermal strain					
ΔRHB1	–2 ± 1	–2 ± 1	–2 ± 1	0.9	.411
ΔRHB2	–2 ± 1	–2 ± 1	–3 ± 0	2.9	.073

Abbreviations: bpm, beats per minute; RHB, rehabilitation.

[a] ΔRHB1, change in variable from end of RHB1 to end of drill 2; ΔRHB2, change in variable from end of RHB2 to end of drill 4. A 1-way analysis of variance to test for differences between groups was used for each ΔRHB with post hoc group comparisons, if necessary, to determine whether forearm cooling reduced any variable during RHB.

[b] Forearm cooling reduced gastrointestinal temperature more than the control or head-cooling condition.

search[36] indicated that barriers between cryotherapy and skin degrade the skin and intramuscular cooling underneath.

Head cooling did not significantly lower HR. With increased T_{GI} and high ambient temperatures, blood was likely shunted to the periphery to allow heat transfer to the environment as a means of cooling, thus increasing HR to maintain cardiac output. The gel pack may not have caused sufficient constriction of the blood vessels in the head to increase central blood volume and decrease cardiovascular strain. Because T_{GI} and HR are used together to calculate the physiological strain index score, it is reasonable that HC did not have a significant effect on the outcome measure.

Head cooling also had no effect on thermal sensation. Although the firefighters in the HC group reported feeling cooler, the difference was not statistically or practically significant (only 1 unit on the scale). Reasons already provided to explain the lack of differences in T_{GI} (ie, decreased surface area of contact, contact material) could, in addition, explain the lack of effect on thermal sensation. Anecdotally, the firefighters stated that any cooling sensation they felt diminished very quickly once they started working, similar to the findings with a ballistic helmet-cooling–pad.[25]

Efficacy of FC During Rehabilitation

The second research aim was to evaluate if FC reduced T_{GI} during RHB compared with groups using no accessory device. The change in T_{GI} during RHB was greater in the FC group than in the CON and HC groups. The absolute T_{GI} was lower by the end of each RHB as well. Forearm cooling also reduced physiological strain index scores after both RHB intervals compared with the other groups but did not lower HR or thermal sensation. These results may be due to the large temperature gradient, the medium of heat transfer, and the exposed surface area.

The 5°C water temperature we used in the immersion arm troughs was much lower than that used by previous researchers[17,18,20–22,26–28] examining this cooling mechanism. Those reported or calculable cooling rates ranged from 0.03°C to 0.07°C/min with water temperatures between 10°C and 20°C.[17,20–22,26,28] However, we chose our water temperature based on the work of Proulx et al,[29] who demonstrated that as water temperature decreased, body temperature cooling rates improved. We were able to maintain the water temperature with periodic ice additions that ensured the temperature gradient remained substantial (5°C versus approximately 39°C) and resulted in a greater cooling rate (0.10°C/min). This enabled heat to be removed from the body at a faster rate during the RHB, ultimately affecting the T_{GI}. It is important to highlight that T_{GI} returned to baseline or lower in the FC group by the end of each RHB time frame. Even in studies in which forearm cold-water immersion successfully reduced body temperature compared with control, none of the interventions returned firefighters to baseline temperature.[17,20–22,28] We believe the 5°C water temperature was the key factor in our statistical and clinical findings compared with previous research. Additionally, during FC, both the length and circumference of the elbow, arm, and hand were subjected to heat dissipation (ie, increased surface area exposed to water). The more skin surface is exposed to cold water, the higher the cooling rate.[30] However, manufacturers of FC devices cannot yet claim to protect firefighters from experiencing potentially dangerous hyperthermia in more extreme situations.

Immersion of extremities is of interest to firefighter companies as a means to lower body temperature while in the field. Previous investigators[27] have compared forearm with leg water immersion to determine the effectiveness of each scenario. Firefighters exhibited no differences in rectal temperature between conditions, which suggests that both are viable options for reducing body temperature. Practically, firefighters who need to return to an emergency after an RHB interval cannot remove their bunker trousers for leg immersion. Authors[17] examining the individual and combined effects of forearm water immersion and cooling vests did not report a difference between the combined techniques and forearm immersion alone. Forearm water immersion is cost effective, as water and ice are more readily available than the freezer units needed to store cooling vests appropriately. Thus, forearm water immersion alone is both practical and physiologically beneficial for field RHB scenarios.

Occupational and military water-immersion research on HR has provided an inconsistent message thus far.[37] In the current study, the FC group had a lower HR at the end of both RHB intervals, but the difference was not statistically significant. However, the lower HR combined with the significantly lower T_{GI} did result in a reduced physiological strain index score. When faced with an increasing body temperature during exercise, the body's dilemma of splitting the finite blood supply between cardiovascular and thermoregulatory demands results in overall physiological strain.[11,38] When thermoregulatory demands can be diminished using rest intervals, accessory cooling mechanisms, or a combination thereof, cardiovascular stress is also lowered. In our study, the rest during RHB combined with FC helped to diminish physiological strain.

The absolute T_{GI} at the end of each drill did not differ in the FC group compared with the CON and HC groups. Greater rises in T_{GI}, HR, and physiological strain index scores were noted in the FC group compared with the CON group during FFA drills 3 and 4. However, this was because these variables were significantly reduced (returned to near baseline) during RHB1, allowing firefighters to work harder and decreasing thermoregulatory demands upon the blood supply when they returned to the drills. In the CON and HC groups, these measures remained elevated during RHB; therefore, participants were unable to work as hard and thus the rise in physiological variables during FFA drills was smaller.

Our research aims included the evaluation of perceptual sensation in addition to physiological variables. Forearm immersion did not lower thermal sensation in the present study, which contrasts with previous investigations of the same cooling modality.[17,20,27,39] Authors[39] examining firefighters have observed that thermal sensation is a poor indicator and that it overpredicts body temperature 80% of the time. A cooling device that lowers body temperature but does not lead to an inappropriately low thermal sensation could be considered safer.

Although T_{GI} and HR rose similarly between groups during the first 2 FFA drills, differences in these variables were noted during FFA drill 3 after T_{GI} returned to baseline in the FC group but not in the CON or HC group during

RHB1. Physical effort and the intensity at which firefighters performed the drills after RHB1 may have been factors in the HR and T_{GI} differences. Firefighters were allowed to self-pace during the FFA drills, which may have resulted in their protecting themselves from reaching a critical threshold[10] for T_{GI} and strategically lowering physiological stress.[40] However, when firefighters cannot self-pace (ie, an actual fire call), T_{GI} and HR may rise to greater extents than in this protocol because the firefighters will not have the option to voluntarily decrease their work intensity.

Our primary research aim was to evaluate the efficacy of 2 cooling devices in attenuating the rise in or reducing T_{GI}. The HC device failed to attenuate the rise in T_{GI} during FFA and, therefore, it should not be recommended for this purpose. Forearm cooling effectively reduced T_{GI} during RHB. Further, the rises in other physiological (HR and physiological strain index) and perceptual (thermal sensation) variables during FFA were not attenuated by head cooling, whereas FC was effective in reducing physiological variables during RHB. However, FC did not attenuate the rise in T_{GI} during the ensuing drills, suggesting that the observed reduction in T_{GI} during RHB may have allowed these firefighters to work at a higher intensity during subsequent drills compared with the CON and HC groups. Use of the FC device during RHB can be recommended while firefighters are actively engaged in the field to promote the return of T_{GI} and physiological strain to baseline values; although this may not attenuate the subsequent rise in T_{GI}, it may allow the firefighter greater work and heat-storage capacity during subsequent activity.

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