

Polar Life Pod Versus Ice Sheet Cooling After Simulated Military Conditioning Exercise

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Context: Exertional heat stroke (EHS) is a leading cause of death in athletes and firefighters. The Polar Life Pod (PLP) and ice sheet cooling (ISC) are 2 of the more portable cooling techniques to treat EHS and show promise for treating patients when large volumes of water or immersion devices (eg, tubs) are not available. Ideal cooling rates consistent with excellent EHS prognoses exceed $0.16^{\circ}\text{C}/\text{min}$, and acceptable rates range from $>0.08^{\circ}\text{C}/\text{min}$ to $0.16^{\circ}\text{C}/\text{min}$. No researchers have compared the cooling effectiveness of the PLP, a body bag-like device, with ISC after simulated military conditioning exercise.

Objective: To determine whether the PLP and ISC reduce rectal temperature (T_{REC}) differently and at acceptable or ideal cooling rates.

Design: Crossover study.

Setting: Laboratory.

Patients or Other Participants: Fourteen participants (10 men, 4 women; age = 22 ± 3 years, height = 168.5 ± 7.8 cm, mass = 73.8 ± 17.8 kg) completed the study.

Intervention(s): Participants donned a military uniform and rucksack and marched in the heat (approximate temperature = 37.5°C ; approximate relative humidity = 40%) until T_{REC} was 39.5°C . After undressing, they were wrapped in bed sheets

presoaked in ice water (temperature $\leq 0.89^{\circ}\text{C} \pm 0.33^{\circ}\text{C}$) or lay in the PLP filled with 151.4 ± 3.8 L of water (temperature $< 8.73^{\circ}\text{C} \pm 2.31^{\circ}\text{C}$) until T_{REC} was 38°C .

Main Outcome Measure(s): Rectal temperature, cooling durations, and calculated T_{REC} cooling rates.

Results: Exercise duration did not differ between trials (PLP = 50.5 ± 9.9 min, ISC = 48.9 ± 10.9 min; $P = .38$). Polar Life Pod cooling rates differed from ISC rates and were ideal, whereas ISC rates were acceptable (PLP = $0.22^{\circ}\text{C}/\text{min} \pm 0.08^{\circ}\text{C}/\text{min}$, ISC = $0.11^{\circ}\text{C}/\text{min} \pm 0.05^{\circ}\text{C}/\text{min}$; $P < .001$).

Conclusions: The Polar Life Pod lowered T_{REC} twice as quickly as ISC and at rates consistent with favorable EHS outcomes. The faster cooling rates of the PLP were likely due to its use of conductive and convective cooling, treating a larger body surface area, and providing a larger heat sink compared with ISC. The Polar Life Pod and ISC can be used to treat EHS, but the PLP is preferred because it reduces T_{REC} faster, uses less ice, and requires the same number of personnel and coolers as does ISC.

Key Words: exertional heat stroke, portability, rectal temperature, thermal sensation

Key Points

- Both the Polar Life Pod (PLP) and ice sheet cooling cooled patients with hyperthermia effectively, but only the PLP met the definition of *ideal cooling* that is consistent with the best exertional heat stroke prognoses.
- The PLP cooled patients with hyperthermia twice as fast as ice sheet cooling did despite using less ice and the same number of coolers and personnel.
- Ice sheet cooling may be a viable cooling strategy if the PLP or traditional cold-water immersion techniques (eg, tubs) are unavailable.

Exertional heat stroke (EHS) is one of the leading causes of sudden death in physically active individuals and military personnel.^{1–3} It often occurs during conditioning and endurance-type exercises (eg, 12-mile [19.31-km] foot march in US Army Ranger School), especially if performed in hot and humid conditions.^{2,4–7} Incidence rates of EHS in the US military vary by service branch and military rank but have been reported to range from 0.04/1000 person-years to 0.72/1000 person-years.⁸ Exertional heat stroke is diagnosed when body core temperature exceeds 40.5°C and central nervous function dysfunction occurs.⁹ If EHS is mismanaged or left untreated, internal organ and skeletal muscle damage occurs, with morbidity and mortality increasing the longer body temperature stays elevated beyond this threshold for cell damage.^{2,4,10}

The current standard of care for patients with EHS includes rectal temperature (T_{REC}) assessment followed by aggressive cooling measures.⁹ Although several cooling modalities exist to treat EHS, the fastest cooling rates and best patient prognoses occur with whole-body cold-water immersion (CWI).^{5,11,12} Several tools exist to perform CWI including stationary tubs, kiddie pools, tarps, and body bags.^{5,11,13–18} Experts recommend immersing as much body surface area in water between 1.7°C (35°F) and 15°C (59°F) to maximize cooling.^{9,19} Stirring or oscillating the water during treatment is also recommended to further aid in decreasing body core temperature via convection. Several authors have recommended minimum cooling-rate thresholds for individuals with EHS based on patient prognostic indicators of health or hospitalization time or cooling rates.^{19–21} In one of the most frequently cited and used

cooling-rate recommendations for EHS, McDermott et al noted that acceptable T_{REC} cooling rates for individuals with EHS are $>0.08^{\circ}\text{C}/\text{min}$, and ideal cooling rates that are consistent with EHS survival and excellent patient prognoses are $>0.16^{\circ}\text{C}/\text{min}$.^{5,12,22}

Survival rates for individuals with EHS are high if EHS is recognized quickly and patients are treated with aggressive whole-body cooling measures within 30 minutes of collapse.^{5,12,23} Unfortunately, CWI with large stationary tubs or pools is often not possible in some military venues where EHS occurs (eg, wilderness and combat arena). Consequently, more portable options of cooling have been investigated and include forearm cooling, ice sheet cooling (ISC), Polar Life Pod (PLP; Polar Products, Inc) cooling, body bag cooling (BAG), and tarp-assisted cooling with oscillation.^{14–18,24–31} The US military recommends using ISC if CWI is not possible.^{32,33} This guidance includes soaking 4 bed sheets in ice water and reapplying them as sheets rewarm or approximately every 3 to 5 minutes (email, August 10, 2022, David DeGroot, PhD, FACSM).³² However, research on the effectiveness of ISC is conflicting, with cooling rates varying from unacceptable to ideal.^{25–28} Comparatively, PLP cooling rates are much higher and meet the operational definition of acceptable to ideal depending on the volume and water temperature used ($0.14^{\circ}\text{C}/\text{min}$ – $0.28^{\circ}\text{C}/\text{min}$).^{16,18,22} Moreover, BAG has been used successfully to cool individuals with hyperthermia (temperature = $0.11^{\circ}\text{C}/\text{min}$) and patients with heat stroke in the prehospital and emergency department settings (cooling rate range, $0.03^{\circ}\text{C}/\text{min}$ to $0.16^{\circ}\text{C}/\text{min}$).^{17,29,30,34} It may also offer an effective enroute cooling strategy to minimize damage caused by treatment delays while patients are being transported to advanced medical care.³¹ Consequently, the PLP and BAG may offer alternatives to ISC given that they require less ice and similar numbers of coolers and support staff. Understanding how PLP cooling reduces hyperthermia compared with ISC may allow for more effective treatment of individuals with heat emergencies in the military and may save lives.

No researchers have compared the cooling effectiveness of the PLP, a body bag–like device, with ISC in individuals with hyperthermia after simulated military conditioning exercise in the heat. Therefore, the purpose of this study was 2-fold: to determine if (1) the PLP or ISC reduced T_{REC} at acceptable or ideal rates after exercise in the heat while wearing a military combat uniform and (2) T_{REC} cooling rates differed between cooling methods. The hypothesis was that PLP cooling rates would be faster than ISC rates and the only cooling strategy to meet the threshold of ideal rates (ie, $>0.16^{\circ}\text{C}/\text{min}$) that are consistent with excellent prognoses for patients with EHS.

METHODS

Study Design and Setting

A randomized (testing order), counterbalanced, crossover experimental design guided data collection for this study. The independent variables were cooling method (PLP or ISC) and time (factor levels varied per dependent variable). The dependent variables were cooling durations, T_{REC} , T_{REC} nadir, and subjective responses (eg, Environmental Symptom Questionnaire [ESQ] and thermal sensation scores). The ESQ and thermal sensation scores were

used to quantify participants' perception of heat and whether they experienced and recovered from any heat illness signs and symptoms before, during, and after exercise and cooling. The 16-item ESQ is rated on a 6-point Likert scale with scores ranging from 0 (*not at all*) to 5 (*extreme*). Thermal sensation is rated on a 10-point scale with scores ranging from 0 (*unbearably cold*) to 9 (*unbearably hot*). Cooling duration and raw T_{REC} were used to calculate the overall cooling rate and the cooling rates for each half of cooling. We also measured environmental chamber temperature, relative humidity, wet-bulb globe temperature (WBGT), urine specific gravity, exercise duration, treadmill incline and speed, and the temperature of the water in the cooler to ensure consistency of testing conditions between and within participants. In this paper, *we* refers to the author, his assistant(s), or both.

Participants

Using T_{REC} cooling-rate data from previous PLP and ISC studies, we estimated sample size a priori based on a treatment effect size of $0.16^{\circ}\text{C}/\text{min}$, an α level of .05, 80% power, and an SD of $0.09^{\circ}\text{C}/\text{min}$ and determined 10 participants were needed.^{16,18,25} To increase power and have a similar number of participants as other hyperthermia studies, we tested a convenience sample of 19 healthy, physically active men and women.^{25,35–38} Individuals were excluded from participating if they self-reported the following: (1) an injury or illness that impaired their ability to exercise; (2) any neurological, respiratory, gastrointestinal, esophageal, or cardiovascular diseases diagnosed by a physician; (3) taking any medications with fluid balance or temperature regulation effects; (4) a *sedentary lifestyle* (defined as exercising <30 minutes 3 times per week); (5) a history of heat-related illness in the 6 months preceding data collection; (6) current pregnancy or possibility of pregnancy; or (7) cold allergy.³⁹ Women completed both testing sessions within the first 14 days of menses to ensure consistency in basal body temperature and minimize the effect of menses on body temperature.⁴⁰

Five participants discontinued testing due to the difficulty of the exercise protocol on the first testing day ($n = 4$) or scheduling issues preventing the completion of the second testing day ($n = 1$). A total of 14 participants completed both trials, and 1 participant completed half of the study (Table 1). The participant who completed half of the study was included in the PLP-reported data but was excluded from statistical analysis due to the pairing assumption of the statistical tests. All participants provided written informed consent, and the study was approved by the university's institutional review board.

Procedures

Procedures for this study followed those of other laboratory hyperthermia and ISC studies.^{25,36,37,41} Participants reported for 2 days of testing between 8:00 AM and 4:00 PM during the fall in the southern United States. They were instructed to abstain from exercise for 24 hours and stimulants (eg, caffeine) or depressants (eg, alcohol) for 8 hours before testing days. Participants were instructed to drink water regularly throughout the day preceding testing to ensure their urine was clear or light yellow and to fast for

Table 1. Participant Characteristics

Characteristic	Mean $\pm$ SD
Age, y	22 $\pm$ 3
Sex, n	
Male ^a	10
Female	4
Height, cm	168.5 $\pm$ 7.8
Mass, kg	73.8 $\pm$ 17.8
Body mass index, kg/m ²	26 $\pm$ 5
Body density, g/cc	1.07 $\pm$ 0.01
Body fat, %	13 $\pm$ 6
Body surface area, m ²	1.83 $\pm$ 0.24

^a A total of 11 men and 4 women completed the Polar Life Pod, and 10 men and 4 women completed ice sheet cooling. One participant who completed half the study was included in the Polar Life Pod–reported data but was excluded from statistical analysis due to the pairing assumption of the statistical tests.

2 hours before the start of testing. Compliance with these instructions was self-reported before testing each day.

Approximately 30 minutes before the participants' arrival, we prepared four 37.9-L (10-gal) insulated coolers (model 42021; Igloo) with 1 of 2 mixtures of ice and water. For ISC, we followed military guidance and placed 4 queen-sized bed sheets (100% polyester, 1800 thread count; Bedsure Home) inside the insulated coolers with 24.6 L (6.5 gal) of ice and 13.3 L (3.5 gal) of tap water (approximate temperature = 21.5°C).³² Only 1 sheet was placed in each cooler at a given time. For the PLP, we mixed 15.1 L (4 gal) of ice with 22.7 L (6 gal) of tap water. The PLP ice-to-water ratio consistently produced a water temperature of approximately 5°C, which met manufacturer and professional guidance for water temperature to treat EHS.^{9,42} After the coolers were filled, each cooler was stirred thoroughly, and the temperature at a depth of approximately 30.5 cm (approximately 12 in) in the center of the cooler was recorded with a flexible temperature thermistor (model 401; Advanced Industrial Systems).

When participants arrived, they voided their bladders completely, and a spot urine specific gravity test was administered to assess hydration status (model HDR-P5 digital refractometer; Thermo Fisher Scientific, Inc). If participants were hypohydrated (ie, urine specific gravity > 1.020), they drank approximately 500 mL of water, and urine specific gravity was reassessed 45 minutes later.⁴³ If they were still hypohydrated, they were rescheduled for another testing day. If euhydrated, participants were weighed nude (scale model Defender 5000; Ohaus Corp). Skinfolts (model Baseline skinfold caliper 12-1110; Fabricated Enterprises, Inc) were measured in triplicate at the chest, abdomen, and thigh for men or the triceps brachii, abdomen, and thigh for women.⁴⁴ Skinfolts measurements were averaged at each site and summed to estimate body density and percentage of body fat.^{45,46} Body surface area was also estimated.⁴⁷

Participants donned a heart rate monitor (model Polar FT1; Polar Electro, Inc) and inserted a rectal thermistor (model 401; Advanced Industrial Systems paired to Alpha Technics 5000 thermometer; TE Connectivity) 15 cm past the anal sphincter.⁴¹ They dressed in a US Army combat uniform.⁴⁸ This uniform comprised undergarments including sports bras for women, shorts, socks, t-shirt, and shoes

Table 2. Exercise, Cooling, and Environmental Variables between the PLP and ISC (Mean $\pm$ SD)

Variable	Polar Life Pod (n = 15) ^a	Ice Sheet Cooling (n = 14) ^a
Exercise		
Exercise duration, min	50.5 $\pm$ 9.9	48.9 $\pm$ 10.9
Treadmill incline, % ^b	12 $\pm$ 2	12 $\pm$ 2
Treadmill speed, km/h ^b	4.9 $\pm$ 0.3	4.9 $\pm$ 0.4
Hydration index		
Pre-exercise urine specific gravity	1.009 $\pm$ 0.006	1.009 $\pm$ 0.007
Body mass pre-exercise, kg ^b	73.81 $\pm$ 17.77	73.96 $\pm$ 11.08
Body mass postexercise, kg ^b	72.66 $\pm$ 17.47	72.89 $\pm$ 17.81
Sweat rate, L/h	1.09 $\pm$ 0.39	1.14 $\pm$ 0.35
Posttesting hypohydration, %	1.5 $\pm$ 0.5	1.5 $\pm$ 0.4
Cooler water temperatures, °C^c		
Before participant arrival	5.03 $\pm$ 1.01	1.67 $\pm$ 0.58
End of exercise	4.22 $\pm$ 0.95	0.89 $\pm$ 0.33
Participants half-finished cooling	7.73 $\pm$ 2.15	0.39 $\pm$ 0.25
Postcooling	8.73 $\pm$ 2.31	0.27 $\pm$ 0.19
Environmental conditions		
Temperature, °C	37.5 $\pm$ 0.3	37.6 $\pm$ 0.3
Relative humidity, % ^c	39 $\pm$ 1	41 $\pm$ 2
WBGT, °C ^c	25.5 $\pm$ 0.2	26.1 $\pm$ 0.5

Abbreviation: WBGT, wet-bulb globe temperature.

^a A total of 11 men and 4 women completed the Polar Life Pod, and 10 men and 4 women completed ice sheet cooling. One participant who completed half the study was included in the Polar Life Pod–reported data but was excluded from statistical analysis due to the pairing assumption of the statistical tests.

^b Data were reported descriptively and were not statistically analyzed.

^c Difference between interventions ($P < .05$).

that the participants supplied and a long-sleeved jacket, belt, pants, and a hard helmet that we provided.

They entered an environmental chamber (Cantrol International Inc) and stood on a treadmill (Pro Runner; 3G Cardio) for 10 minutes to acclimate to the heat (approximate temperature = 37°C, approximate relative humidity = 40%, WBGT = 25.5°C). The environmental variables in this study met the military's *white heat flag* status, indicating no heat-related modification to training or the uniform was necessary (Table 2).³² During acclimation, we moved the 4 coolers inside the environmental chamber, and participants rated their thermal sensation and completed the ESQ. After acclimation, they donned a rucksack containing a 9.1-kg plate weight to simulate the weight of equipment carried in the field. They self-selected a treadmill incline and speed they perceived as challenging but achievable. Participants could change the treadmill speed or incline at any time to alter the intensity, but the minimum incline and speed allowed were 2% and 4.8 km/h, respectively. Treadmill incline and speed were recorded every 5 minutes so the same variables and timing of effort could be used on the second day of testing.

When T_{REC} was approximately 39°C during exercise, we stirred the coolers and recorded the temperature in the middle of the coolers. After reaching a T_{REC} of approximately 39.4°C, participants rated their thermal sensation and completed their second ESQ. Rectal temperature was recorded every 5 minutes but monitored continuously to determine when it reached 39.5°C. No fluids were given to participants at any time during exercise to expedite the increase in

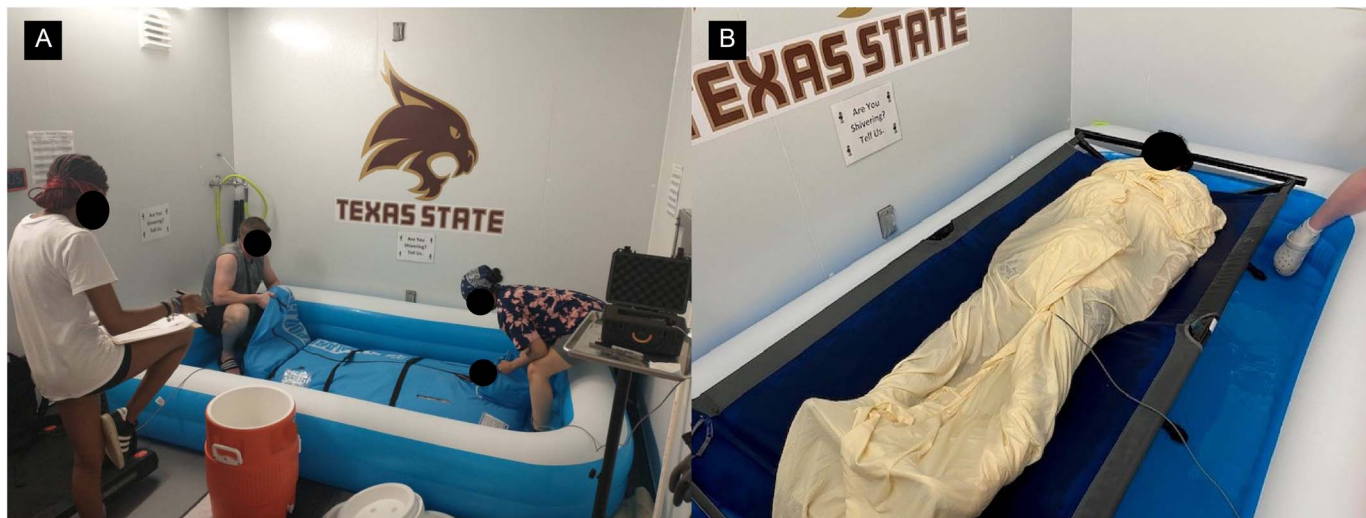


Figure 1. Participants immersed in the, A, Polar Life Pod or, B, ice sheets after marching in the heat while wearing a military combat uniform.

T_{REC} . If they had to urinate during exercise, we stopped the treadmill, and they urinated into a container so we could measure its volume to ensure the accuracy of sweat rate calculations. The exercise protocol was terminated when any of the following occurred: participants reported being too tired to continue the exercise protocol before reaching the target temperature of 39.5°C , they reported or displayed signs or symptoms of severe heat illness (eg, gross unsteadiness), we believed it was in their best interest to stop testing, or T_{REC} reached 39.5°C .

When T_{REC} was 39.5°C , they removed the rucksack, helmet, long-sleeved jacket, pants, t-shirt, and shoes but continued to wear shorts, undergarments (including sports bra), and socks during cooling. Participants completed 1 of 2 interventions. For the PLP, the manufacturer's recommendations for use were followed.⁴² They lay inside the PLP, and if necessary, the end of the unit closest to their feet was folded to minimize water accumulation at the end of the unit. We carefully poured 151.4 L (40 gal) of $4.22^{\circ}\text{C} \pm 0.95^{\circ}\text{C}$ water into the PLP, closed the zipper, and secured the straps on the device (Figure 1A; Table 2). This process took approximately 1.5 minutes. Use of a neck pillow, custom made for use in the PLP, ensured patency of the airway during treatment. The PLP was gently shaken continuously side-to-side during cooling. A thermistor was placed into the water by the participants' neck so water temperature could be recorded during cooling. Half-cooled and final water temperatures were recorded when T_{REC} was 38.75°C and 38°C , respectively.

For ISC, we followed the US military's guidelines.^{32,33} Four bed sheets were soaked continuously in approximately 1°C ice water while participants exercised. When T_{REC} was approximately 39.48°C , 1 bed sheet was removed from a cooler and spread over an oversized canvas cot (214.1 cm long $\times$ 106.4 cm wide $\times$ 50.0 cm high, model BD-82701; Ever Advanced; Figure 1B). Participants only lay on this cot during ISC days to ensure they were not lying in a pool of water during cooling. The cot was made of porous canvas with multiple holes drilled into it to allow water to drain from underneath the participant. This was done based on the assumption that the ground would absorb

any water lost in the transfer of the sheets from coolers to the individual in the field.

When T_{REC} was 39.5°C , participants stopped the treadmill, removed the same clothes as they did for the PLP trial, and lay on the cot and first bed sheet. The other 3 bed sheets were removed from the coolers, wadded up, and placed over the participants' neck, chest and armpits, and groin.³² The sides of the first sheet were pulled over the front of the participants, thereby covering the other 3 sheets. The sheets over the neck, groin, and chest were removed every 3.25 minutes, reimmersed in the coolers for 0.5 minutes, and reapplied in their former spots by every fourth minute of cooling. This ice sheet recharge process continued until T_{REC} was 38°C .

Rectal temperature was recorded every 30 seconds during cooling on both days. A stopwatch was started the moment the water was first poured over participants (PLP trial) or participants lay on the first ice sheet (ISC trial). Participants were asked to self-report any shivering during treatment, and the time of shivering onset, if reported, was recorded. Approximately halfway through cooling ($T_{REC} = 38.75^{\circ}\text{C}$), participants reported thermal sensation a third time, and we remeasured the temperature of the water in the cooler (ISC trial) or water temperature in the PLP. When T_{REC} was 38°C , participants were removed from the PLP or ISC; dried their chests, arms, and legs; and sat in the environmental chamber for 10 minutes. Rectal temperature was measured every 5 minutes during recovery. During this time, they completed their third ESQ and reported their thermal sensation a fourth time. After this recovery period, they removed the rectal thermistor, disrobed completely, towel-dried as best as possible, were weighed nude a second time, and were excused. Participants completed their second testing day at approximately the same time of day (± 2 hours) and at least 72 hours after their first testing day.

Statistical Analysis

Raw T_{REC} and cooling durations were used to calculate T_{REC} cooling rates by dividing the change in T_{REC} at treatment onset and completion by total treatment time. We also

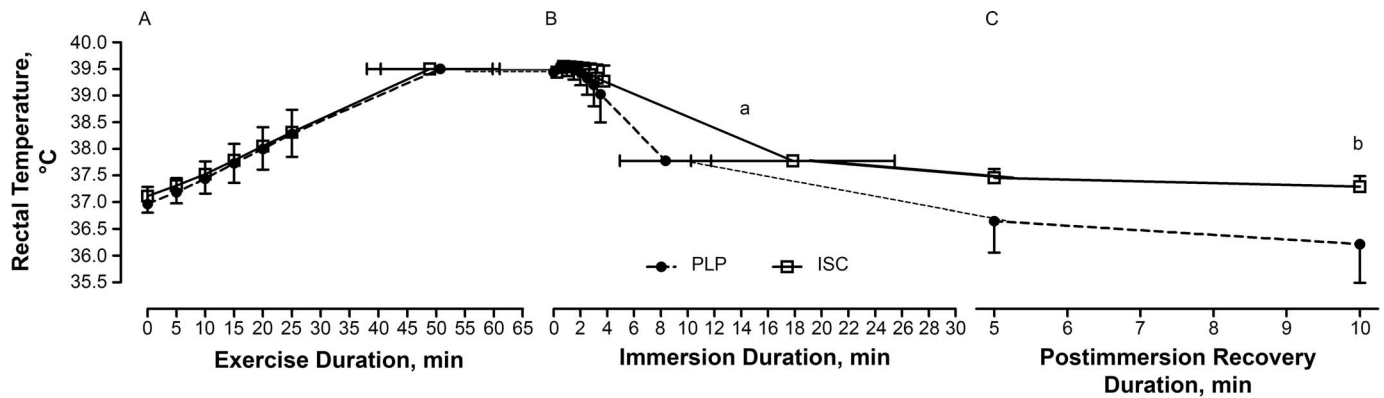


Figure 2. Rectal temperature during, A, exercise, B, immersion, and, C, postimmersion recovery in the PLP and ISC conditions. Time 0 indicates the start of exercise or cooling. X-axis error bars in exercise duration and immersion duration indicate the SD of the final exercise and cooling durations. ^aPolar Life Pod cooling duration < ice sheet cooling duration ($t_{13} = 5.1$, $P < .001$). ^bPolar Life Pod nadir < ice sheet cooling nadir ($z_{13} = 3.3$, $P < .001$).

calculated cooling rates for each half of cooling because cooling rates tend to differ over the course of treatment.⁴⁹ Means and SDs for cooling rates were calculated and assessed for normality. Separate dependent t tests were used to examine differences in aggregate and first half of treatment T_{REC} cooling rates, pre-exercise urine specific gravity, sweat rate, percentage hypohydration, and exercise durations because data were normally distributed. A Wilcoxon signed-rank test for differences in medians was used for T_{REC} nadir and the second half of treatment cooling rates because these data were not normally distributed.

Separate repeated-measures analyses of variance were used to examine differences in thermal sensation, water temperatures, and raw T_{REC} during exercise and cooling between conditions. Because participants required different amounts of time to exercise and cool, we only analyzed raw T_{REC} common to all participants during exercise, cooling, and recovery. For ESQ responses, we summed the scores from the 16 items and created a new cumulative score,³⁵ and we analyzed the data using repeated-measures analyses of variance. Sphericity was assessed using the Mauchly test. Geisser-Greenhouse adjustments to P values and degrees of freedom were made if the sphericity condition was violated. If interactions or main level effects were found, Tukey-Kramer post hoc tests were used to identify differences between cooling methods at each time. Significance was accepted when $P < .05$ (version 2007; Number Cruncher Statistical Software).

RESULTS

Participants self-reported compliance with pretesting instructions and were similarly euhydrated as indicated by urine specific gravity ($t_{13} = 0.14$, $P = .89$; Table 2). They exercised in similar ambient temperatures ($t_{13} = 0.6$, $P = .56$), but the relative humidity ($t_{13} = 2.9$, $P = .01$) and WBGT ($t_{13} = 3.7$, $P = .002$) of the environmental chamber were slightly higher for ISC (Table 2). All participants who completed both trials marched for similar durations ($t_{13} = 0.9$, $P = .38$) using similar treadmill speeds and inclines and achieved a T_{REC} of 39.5°C (Table 2). Sweat rate ($t_{13} = 0.6$, $P = .57$) and percentage hypohydration ($t_{13} = 0.2$, $P = .84$) were not different between conditions, indicating similar levels of hypohydration postexercise.

Rectal temperature increased similarly during exercise on each testing day, and all 14 participants who completed both trials achieved a T_{REC} of 39.5°C ($F_{1,14} = 0.5$, $P = .49$; Figure 2). In the first 3 minutes of cooling, T_{REC} was comparable between conditions ($F_{1,16} = 3.0$, $P = .10$; Figure 2). However, cooling duration was shorter in the PLP than ISC ($t_{13} = 5.1$, $P < .001$). Consequently, the PLP had faster aggregate cooling rates ($t_{13} = 5.7$, $P < .001$) and cooling rates for the first ($t_{13} = 3.9$, $P < .001$) and second ($z_{13} = 3.2$, $P < .001$; Table 3) halves of treatment. Rectal temperature nadir postcooling was lower in the PLP than ISC ($z_{13} = 3.3$, $P < .001$; Figure 2).

We observed an interaction between time and condition for ESQ scores ($F_{2,26} = 11.6$, $P < .001$; Table 4). Pre-exercise ESQ scores differed from postexercise and post-cooling scores in the PLP but only differed from postexercise scores in ISC. Environmental Symptom Questionnaire scores differed between conditions at postcooling ($P < .05$). Similarly, an interaction was observed for thermal sensation ($F_{3,39} = 17.2$, $P < .001$; Table 4). Thermal sensation differed between the PLP and ISC halfway through cooling and postcooling ($P < .05$). Within each condition, pre-exercise thermal sensation differed from halfway through cooling and postcooling ($P < .05$). Eleven participants shivered in the PLP trial, with an average self-reported onset of 3.8 ± 1.2 minutes compared with 3 participants in the ISC trial (12.0 ± 2.3 min).

DISCUSSION

This is the first randomized, experimental study directly comparing the cooling efficacy of the PLP with that of ISC. This study advances the understanding of both the PLP and ISC in several ways. First, it is the only PLP or ISC study in which cooling rates were examined after participants performed a ruck march in the heat while wearing a combat uniform. Combat uniforms, unlike standard workout apparel, cover more body surface area and impair sweat evaporation, leading to greater heat storage.⁵⁰ Concurrently, individuals expend more energy and create more heat when they carry a rucksack because the load results in higher metabolic demand of muscles.⁵¹ Cumulatively, this leads to greater difficulty in thermoregulating, and the individual undergoes higher thermal stress.⁵⁰

Table 3. Cooling Durations and Rectal Temperature Cooling Rates With the Polar Life Pod and Ice Sheet Cooling

Variable	Polar Life Pod (n = 15) ^a	Ice Sheet Cooling (n = 14) ^a
Cooling duration, min, mean ± SD		
Aggregate	8.4 ± 3.4 ^d	17.7 ± 7.6
First half of treatment ^b	5.3 ± 2.2 ^d	8.9 ± 3.8
Second half of treatment ^c	3.0 ± 1.4 ^d	8.7 ± 4.6
Cooling rate, °C/min		
Aggregate, mean ± SD	0.22 ± 0.08 ^d	0.11 ± 0.05
First half of treatment, mean ± SD ^b	0.18 ± 0.06 ^d	0.11 ± 0.04
Second half of treatment, median (IQR) ^c	0.25 (0.23) ^d	0.10 (0.09)

Abbreviation: IQR, interquartile range.

^a A total of 11 men and 4 women completed the Polar Life Pod, and 10 men and 4 women completed ice sheet cooling. One participant who completed half the study was included in the Polar Life Pod–reported data but was excluded from statistical analysis due to the pairing assumption of the statistical tests.

^b First half of treatment was the cooling rate of rectal temperature from 39.5°C to 38.75°C.

^c Second half of treatment was the cooling rate of rectal temperature from 38.75°C to 38°C.

^d Difference between interventions ($P < .05$).

Second, participants exercised to the highest T_{REC} (ie, 39.5°C) reported in all ISC studies performed under controlled laboratory conditions.^{25,27,28} Third, we examined perceptual indicators of health and heat stress before, during, and after cooling interventions. Finally, we delimited the research so similar amounts of resources (eg, coolers and support staff) were available in each condition.

Three main clinical observations came from this study. First, the PLP cooled individuals with hyperthermia twice as fast as ISC despite requiring similar amounts of preparation and resources. Second, ISC cooling rates met the operational definition of *acceptable* ($>0.08^{\circ}\text{C}/\text{min}$), whereas PLP cooling rates were *ideal* ($>0.16^{\circ}\text{C}/\text{min}$) for patients with EHS.²² Third, participants reported fewer lingering heat illness signs and symptoms and more comfortable thermal sensation scores during recovery with ISC than the PLP. Although ensuring patient survivability is prioritized over patient comfort, these subjective data indicate differences in how patients react to each cooling treatment and may provide guidance for how clinicians can help patients during recovery (eg, necessity of rewarming methods).

The observation that PLP cooling rates were ideal and consistent with life-saving BAG cooling rates in real patients with heat stroke is consistent with recent literature.^{5,16,18,29–31} In 2 similar PLP studies using a hyperthermia model, authors demonstrated PLP cooling rates were dependent on water temperature and volume in healthy participants who exercised to a T_{REC} of 39.5°C and were cooled in the PLP.^{16,18} When 202 L to 211 L (54 gal to 56 gal) of 3.2°C, 10°C, or 15°C water was used inside the device, cooling rates were $0.28^{\circ}\text{C} \pm 0.09^{\circ}\text{C}$, $0.18^{\circ}\text{C} \pm 0.07^{\circ}\text{C}$, or $0.14^{\circ}\text{C} \pm 0.09^{\circ}\text{C}$, respectively. In this study, we used 151.4 L (40 gal) of 4.22°C water and still noted excellent cooling despite using less water in the PLP than the other authors.^{16,18} Consequently, the ice-water temperatures were able to compensate for the smaller water volume used

Table 4. Summative Environmental Symptoms Questionnaire and Thermal Sensation Scores With the Polar Life Pod or Ice Sheet Cooling (Mean ± SD)

Variable	Polar Life Pod (n = 15)	Ice Sheet Cooling (n = 14)
Environmental Symptoms Questionnaire ^a		
Pre-exercise	3 ± 4	2 ± 4
Postexercise	20 ± 14 ^c	25 ± 16 ^c
Postcooling	12 ± 11 ^{c,d}	3 ± 4
Thermal sensation ^b		
Pre-exercise	4.6 ± 0.7 ^c	4.5 ± 0.5 ^c
Postexercise	6.7 ± 0.9	6.9 ± 0.8
Halfway through cooling	1.5 ± 0.8 ^{c,d}	3.3 ± 0.9 ^c
Postcooling	2.5 ± 0.6 ^{c,d}	3.4 ± 0.6 ^c

^a The 16-item Environmental Symptoms Questionnaire is rated on a 6-point Likert scale with scores ranging from 0 (*not at all*) to 5 (*extreme*).

^b Thermal sensation is rated on a 10-point scale with scores ranging from 0 (*unbearably cold*) to 9 (*unbearably hot*), with 4 indicating *comfortable*.

^c Different from pre-exercise within each condition ($P < .05$).

^d Difference between interventions ($P < .05$).

in this study and were still able to maintain a high thermal gradient that encouraged rapid cooling.

Body core temperature afterdrop and hypothermia can be problematic when using the PLP and CWI.^{18,52} The risk of afterdrop after removing patients from the PLP or CWI does not justify using inferior methods of cooling; however, clinicians must be prepared to rewarm patients due to the PLP and CWI's effectiveness. In this study, both interventions continued to reduce T_{REC} during recovery, but nadir was approximately 1°C lower in the PLP. The participants' T_{REC} nadir in ISC ($37.56^{\circ}\text{C} \pm 0.18^{\circ}\text{C}$) and the PLP ($36.59^{\circ}\text{C} \pm 0.65^{\circ}\text{C}$) were comparable with that reported by others who monitored body core temperature for 15 minutes postcooling.^{18,25} Afterdrop and hypothermia can be minimized by continuously monitoring T_{REC} and using higher T_{REC} stopping thresholds for treatment (eg, 39°C). Clinicians may need to have rewarming tools (eg, heated blankets) available after the PLP and any technique that uses CWI. Aggressive, active rewarming measures would likely not be needed with ISC given the small amount of T_{REC} afterdrop that occurred during recovery.

Although the PLP cooled at ideal rates, ISC rates were slower ($0.11^{\circ}\text{C}/\text{min} \pm 0.05^{\circ}\text{C}/\text{min}$) and only met the acceptable cooling threshold for patients with EHS ($>0.08^{\circ}\text{C}/\text{min}$).²² Cooling rates for ISC vary in the literature and should be scrutinized by publication date because the US military changed the ISC protocol in 2016 from 1 cooling sheet to the protocol used in this study. In 2 studies conducted before 2016, researchers examined T_{REC} cooling rates with ice towels or ISC and reported unacceptable cooling rates of approximately $0.06^{\circ}\text{C}/\text{min}$.^{27,28} Notable differences of these studies from the current investigation include participants having lower T_{REC} postexercise (38.75°C to 39.25°C), wearing less clothing during exercise (workout apparel versus combat uniform), having fewer ice sheets applied to the body, using different water temperatures for soaking the sheets (3°C to 14°C), and reapplying ice sheets at different intervals (every 2 or 5 minutes).^{27,28}

All these methodological differences would decrease the thermal gradient and explain the slower cooling rates than reported in this study.

After 2016, authors of 2 studies examined the effectiveness of ISC in a clinical population with EHS and exertional heat illness, and authors of 1 study examined ISC in a laboratory environment.^{25,26,53} In the laboratory study, participants clothed in normal workout apparel exercised in the heat (temperature = 40°C, relative humidity = 30%) to mild hyperthermia ($T_{REC} = 38.8^{\circ}\text{C} \pm 0.39^{\circ}\text{C}$).²⁵ They underwent the most current military ISC protocol but still cooled at a mean rate of 0.068°C/min.³² The ISC rates in our study were likely higher because participants wore combat uniforms during exercise. This would have increased skin temperature and the thermal gradient between the skin and ice sheets, thereby helping participants cool faster.⁵⁰ Conversely, DeGroot et al retrospectively analyzed 363 patients with EHS who received ISC while enroute to the emergency department.²⁶ Patients with $T_{REC} \geq 39^{\circ}\text{C}$ and $<39^{\circ}\text{C}$ had ISC cooling rates of 0.16°C/min $\pm$ 0.08°C/min and 0.03°C/min $\pm$ 0.04°C/min, respectively. When ISC was applied with chilled saline in 5 military patients with an initial $T_{REC} \geq 40.6$, all patients survived and had cooling rates between 0.075°C/min and 0.13°C/min (mean = 0.09°C/min $\pm$ 0.03°C/min).⁵³ The current data are consistent with these cooling rates and suggest ISC can be used successfully for patients with EHS. Although all the patients survived with ISC treatment, cooling strategies that reduce T_{REC} as quickly as possible must be used to prevent the possibility of long-term disability or complications stemming from treatment delays or inadequate cooling.^{26,54}

We propose several reasons why every participant cooled faster in the PLP. First, the PLP used convective and conductive cooling. The combination of water oscillation and CWI is well known to produce excellent cooling rates and EHS survival rates.⁵ Second, the PLP water immersion provided greater cooling capacity due to the larger heat sink and energy transfer capabilities of water compared with modalities performed in the air.⁵⁵ Third, although both interventions covered almost the entire body, the water in the PLP likely came into contact with more body surface area because the ice sheets were not in direct contact with some body areas (eg, medial lower legs). Given that EHS morbidity and mortality are a function of how long patients' temperatures remain elevated, the immediate treatment goal is to decrease body temperature below 39°C as quickly as possible.^{9,10,19} Extrapolating the cooling rates in this study to patients with EHS temperatures (eg, 43°C) that are lowered to 39°C indicates only the PLP would meet the expert recommendation to reduce T_{REC} in <30 minutes (PLP, 18.2 minutes versus ISC, 36.4 minutes).⁹ Therefore, clinicians may want to use the PLP rather than ISC in military settings where access to ice is challenging because of the PLP's superior cooling and similar preparation requirements and resources.

Two final considerations should be noted between treatments. First, participants perceived they were warmer, shivered less, and self-reported less intense heat-illness symptoms during and after ISC than the PLP. This finding is consistent with that of a previous study and can likely be explained by the slower rate of cooling of ISC, resulting in more time elapsing postexercise to resolve their exercise-

induced heat-illness symptoms and a slightly higher WBGT during the ISC trial.¹⁸ In addition, posttreatment ESQ score differences between conditions can be attributed to high goosebumps scores and the summation of miscellaneous other mild symptoms with the PLP. However, when 10°C or 15°C water was used in the PLP, both thermal sensation and ESQ scores improved considerably compared with when ice water (3°C) was used, albeit at the expense of slower cooling rates.^{16,18} Therefore, water closer to 10°C may be optimal in the PLP to balance the perceptual indicators and minimize overcooling and T_{REC} nadir while still producing ideal cooling rates. Second, approximately 50% of the water remained in the coolers after ISC. In comparison, the PLP has a large opening at 1 end where water could escape if a clinician did not act to preserve the water postcooling. Consequently, ISC possibly could be used for >1 patient with EHS, whereas care would be needed to ensure the water remained in the PLP for subsequent patients with EHS. This practical consideration and the prevalence of EHS at an event should be considered when creating EHS policy and procedure documents.

This study had several limitations. First, participants supplied their own t-shirts, undergarments, shorts, and shoes, which varied in length, size, fabric composition, and style. We provided the other components of the uniform (eg, jacket, belt, pants, and helmet) to ensure consistency between participants. Second, we only used 4 coolers filled with ice and water in the PLP trial. The PLP holds up to 227.1 L (60 gal) of water, and the manufacturer advises having 6 coolers available in the event of a heat illness.⁴² We intentionally delimited this study to 4 coolers so similar amounts of resources would be used each testing day. Faster PLP cooling rates than those reported in this study have been observed when larger water volumes were used.^{16,18} Third, some water leaked out of the body bag or was spilled in the process of cooling; thus, we are only confident of the initial water volume prepared for the PLP. Fourth, the ice and water volume inside each cooler decreased and varied as we transferred ice sheets between the participants and coolers during treatment. Participants requiring longer treatments had more water lost from the coolers due to more recharge periods, which explains why water temperature in the coolers decreased over the course of testing as more ice was left behind in the cooler (Table 2). Given that the water temperature inside the coolers remained $\leq 1.7^{\circ}\text{C}$ throughout testing and >50% of the water volume in the cooler remained after testing, we are confident that the ice sheets were recooled effectively during the 30-second resubmersion periods. Fifth, rather than duplicate the same water temperatures for each condition, we opted for a more externally valid test by following military and expert guidance for ISC and CWI.^{9,32,33} Consequently, the water temperatures between conditions differed by approximately 3°C. However, both conditions, as evidenced by the cooling rates, provided a thermal gradient encouraging cooling and provided valid data for how these tools are being used in the field. Sixth, the cooling-rate thresholds recommended by McDermott et al were used to clinically interpret the effectiveness of the cooling rates in this study.²² Other authors have indicated adequate or insufficient cooling-rate thresholds above or below a single cutoff point of 0.15°C/min, respectively.^{20,21} Given that PLP cooling rates were well above all these thresholds, the only potential

discrepancy in the interpretation in this study surrounds the effectiveness of ISC. Considering the survival of several patients with EHS when treated with ISC, we believe ISC can be used to save patients with EHS when CWI is unavailable or prohibited.^{26,53} However, more research is needed to determine what is considered a minimally acceptable or ideal cooling rate for EHS and whether cooling rate alone or other criteria (eg, morbidity, mortality, and patient perceptions) should be used to describe a modality as ideal or adequate. Finally, participants did not experience EHS. This is a safety limitation of all university-based laboratory studies. However, participants had either a higher or similar T_{REC} as in other ISC studies and reported signs and symptoms of heat illness and perceptions of being very hot before treatment.^{25–27} Regardless, in much of the research in which the effectiveness of cooling modalities has been investigated, an exercise-induced hyperthermia model rather than EHS has been used. Clinicians should continue to use their clinical judgment when treating EHS and applying information from hyperthermia studies to their clinical practice.

CONCLUSIONS

The PLP cooled participants with hyperthermia 55% faster than ISC and was the only cooling intervention to meet the ideal cooling-rate threshold that is consistent with EHS survival and the best patient-related outcomes (eg, survival rates, less internal organ damage, and fewer neurologic sequelae at discharge).^{5,22,23,30} Given that ice is difficult to maintain in the field and both interventions required the same number of coolers and support staff for implementation, the PLP should be used over ISC in the military arena when EHS is suspected. Future research should be done to investigate whether a minimal water volume exists to maintain the ideal cooling rate of the PLP and whether the water in a PLP can be salvaged to treat multiple individuals, as this remains a major advantage of ISC.

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