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Polar Life Pod Cooling versus Ice Sheet Cooling following Simulated Military Conditioning Exercise

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ABSTRACT

Context: Exertional heatstroke (EHS) is a leading cause of death in athletes and the warfighter. Polar Life Pod (PLP) and ice sheet cooling (ISC) are two of the more portable cooling techniques to treat EHS and show promise for treating patients when large volumes of water or immersion devices (e.g., tubs) are not available. "Ideal" cooling rates consistent with excellent EHS prognoses exceed 0.16°C/min while "acceptable" rates are between >0.08°C/min and 0.15°C/min. No research has compared the cooling effectiveness of the Polar Life Pod (PLP), a body bag-like device, to ISC following simulated military conditioning exercise.

Objective: Determine if PLP or ISC reduced rectal temperature (T_{REC}) differently and at 'acceptable' or 'ideal' cooling rates.

Design: Randomized, counterbalanced, crossover study

Setting: Laboratory

Patients or Other Participants: Fourteen participants (10 men, 4 women; age: 22±3y; mass:73.8±17.8kg; ht:168.5±7.8cm)

Interventions: Participants donned a military uniform and rucksack and marched in the heat (temperature=~37.5°C; relative humidity=~40%) until T_{REC} was 39.5°C. Then they undressed and were wrapped in bed sheets presoaked in ice water (≤0.89±0.33°C) or lay in PLP filled with water (151.4±3.8L; 4.22±0.95°C) until T_{REC} was 38°C.

Main Outcome Measures: T_{REC} and cooling durations; calculated T_{REC} cooling rates

Results: Participants exercised in similar clothing, environmental conditions, and durations (PLP=50.5±9.9min, ISC=48.9±10.9min, *P*=0.38). PLP cooling rates differed from ISC and were 'ideal' whilst ISC rates were 'acceptable' (PLP=0.22±0.08°C/min; ISC=0.11±0.05°C/min, P<0.001).

Conclusions: PLP lowered T_{REC} twice as quickly as ISC and at rates consistent with favorable EHS outcomes. PLP's faster cooling rates were likely due to it utilizing conductive and convective cooling, treating a larger body surface area, and providing a larger heat sink than ISC. PLP and ISC can be utilized to treat EHS, but PLP is preferred because it reduced T_{REC} faster, utilized less ice, and required the same number of personnel and coolers as ISC.

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

Take Home Points:

- Both PLP and ISC cooled hyperthermic patients effectively but only PLP met the definition of 'ideal cooling' that is consistent with the best EHS prognoses.
- PLP cooled hyperthermic participants twice as fast as ISC despite utilizing less ice and the same number of coolers and personnel.
- ISC may be a viable cooling strategy if PLP or traditional cold-water immersion techniques (e.g., tubs) are unavailable.

INTRODUCTION

Exertional heatstroke (EHS) is one of the leading causes of sudden death in physically active individuals and the military.[1-3] EHS often occurs during conditioning[4-6] and endurance-type exercises (e.g., 12-mile foot march in Army Ranger School)[2] especially if performed in hot and humid conditions.[5, 7] Incidence rates of EHS in the United States military vary by service branch and military rank but have been reported from 0.04/1000 person-years to 0.72/1000 person-years.[8] EHS is diagnosed when body core temperature exceeds 40.5°C and central nervous function dysfunction occurs.[9] If 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 EHS patients includes rectal temperature (T_{REC}) assessment followed by aggressive cooling measures.[9] While several cooling modalities exist to treat EHS, the fastest cooling rates[11] and best patient prognoses[5, 12] occur with whole-body cold-water immersion (CWI). Several tools exist to perform CWI including stationary tubs,[5, 13] kiddie pools, tarps,[14, 15] and body bags.[11, 16-18] Experts recommend immersing as much body surface area in water between 1.7° and 15°C (35°F to 59°F) to maximize cooling.[9, 19] Stirring or oscillating the water during treatment is also recommended to further aid in lower body core temperature via convection. Several authors have recommended minimum cooling rate thresholds for EHS victims based on patient prognostic indicators of health or hospitalization time[20] or cooling rates.[19, 21] One of the most frequently cited and utilized cooling rate recommendations for EHS notes 'acceptable' T_{REC} cooling rates for EHS victims are >0.08°C/min while 'ideal' cooling rates that are consistent with EHS survival and excellent patient prognoses are >0.16°C/min.[5, 12, 22]

EHS survival rates 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 (e.g., wilderness, combat arena). Consequently, more portable options of cooling have been investigated and include forearm cooling,[24] ice sheet cooling (ISC),[25-28] Polar Life Pod (PLP) cooling,[16, 18] body bag cooling (BAG),[17, 29-31] and tarp-assisted cooling with oscillation.[14, 15] The United States 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[32] or approximately every 3-5 minutes (author correspondence with Dr. David DeGroot, 2022). However, research on the effectiveness of ISC is conflicting with cooling rates varying from 'unacceptable'[25, 27, 28] to 'ideal.'[26] Comparatively, PLP cooling rates are much higher and meet the operational definition[22] of 'acceptable'[16] to 'ideal'[18] depending on the volume and water temperature utilized (0.14°C/min to 0.28°C/min). Moreover, BAG has been used successfully to cool hyperthermic individuals (0.11°C/min)[34] and heatstroke patients in the pre-hospital[30] and emergency room settings (cooling rates vary from 0.03°C/min to 0.16°C/min).[17, 29] It may also offer an effective *enroute* cooling strategy to minimize damage caused by treatment delays while patients are on the way to advanced medical care.[31] Consequently, PLP and BAG may offer alternatives to ISC given they require less ice and similar amounts of coolers and support staff. Understanding how PLP cooling reduces hyperthermia compared to ISC may allow for more effective treatments of heat emergencies in the military and may save lives.

No research has compared the cooling effectiveness of the PLP, a body bag-like device, to ISC in hyperthermic individuals following simulated military conditioning exercise in the heat. Therefore, the purpose of this study was two-fold. First, we determined if PLP or ISC reduced T_{REC} at 'acceptable' or 'ideal' rates following exercise in the heat while wearing a military combat uniform. Second, we determined if T_{REC} cooling rates differed between cooling methods. We hypothesized PLP cooling rates would be faster than ISC and be the only cooling strategy to meet the threshold of 'ideal rates' (i.e., >0.16°C/min) that are consistent with excellent EHS patient prognoses.

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 the dependent variable). The dependent variables were cooling durations, T_{REC}, T_{REC} nadir, and subjective responses (e.g., environmental symptom questionnaire [ESQ] and thermal sensation scores). The ESQ and thermal sensation scores were useful to quantify how hot participants felt and whether they experienced and recovered from any heat illness signs and symptoms before, during, and after exercise and cooling. Cooling duration and raw T_{REC} were used to calculate overall cooling rate and cooling rates for each half of cooling. We also measured environmental chamber temperature, relative humidity, and wet-bulb globe temperature (WBGT), urine specific gravity, exercise duration, treadmill incline and speed, and cooler water temperature to ensure consistency of testing conditions between and within participants.

Participants

Using T_{REC} cooling rate data from prior PLP[16, 18] and ISC studies,[25] we estimated sample size *a priori* with the following assumptions: treatment effect size of 0.16°C/min, an alpha level of 0.05, 80% power, and a standard deviation of 0.09°C/min. We needed 10 participants for statistical significance. To increase power and have a similar number of participants as other hyperthermia studies,[25, 35-38] we tested a convenience sample of 19 healthy, physically-active men and women. Unfortunately, 5 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). Thus, 14 participants completed both trials and one participant completed half of the study (Table 1). The participant that 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.

Individuals were excluded from participating if they self-reported: (1) an injury or illness which 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),[39] (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. Females 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] All procedures were approved by an institutional review board and participants provided written consent before participation.

Procedures

Procedures for this study followed other laboratory hyperthermia studies[36, 37, 41] and ISC studies.[25] Participants reported for two days of testing between 0800 and 1600 during the Fall in the Southern United States. They were instructed to abstain from exercise (24 hours) and stimulants (e.g., caffeine) or depressants (e.g., alcohol) for 8 hours before testing days. We instructed participants to drink water regularly throughout the day preceding testing to ensure their urine was clear or light yellow and to fast for 2 hours before the start of testing. Compliance with these instructions was self-reported before testing each day.

Approximately 30 minutes before participants arrival, we prepared four, 37.9 L (10 gal) insulated coolers (Igloo, #42021, Katy, TX) with one of two mixtures of ice and water. For ISC, we followed military guidance[32] and placed four queen-sized bed sheets (100% polyester, 1800 thread count, Bedsure Home, New York, NY) inside the insulated coolers with 24.6 L (6.5 gal) of ice and 13.3 L (3.5 gal) of tap water (~21.5°C). Only one sheet was placed in each cooler at a given time. For PLP, we mixed 15.1 L (4 gal) of ice with 22.7 L (6 gal) of tap water. PLP ice/water ratio consistently produced water ~5°C which met manufacturer[42] and professional[9] guidance for water temperature to treat EHS. Once the coolers were filled, we stirred each cooler thoroughly and the temperature at a depth of ~30.5 cm (~12 in) in the center of the cooler was recorded with a flexible temperature thermistor (#401, Advanced Industrial Systems; Prospect, KY).

When participants arrived, they voided their bladders completely and a spot urine specific gravity test was administered to assess hydration status (HDR-P5 digital refractometer, Thermo Fisher Scientific, Inc, Waltham, MA). If participants were hypohydrated (i.e., >1.020),[43] they drank ~500 mL of water and urine specific gravity was reassessed 45 minutes later. If they were still hypohydrated, they were rescheduled for another testing day. If euhydrated, participants were weighed nude (Defender #5000, Ohaus Corp, Parsippany, NJ). We measured skinfolds at the chest, abdomen, and thigh (men) or the triceps brachii, abdomen, and thigh (women) in triplicate[44] (Baseline skinfold caliper #12-1110, Fabricated Enterprises, Inc, White Plains, NY).

Skinfolds were averaged at each site and summed to estimate body density[45] and percent body fat.[46] Body surface area was also estimated.[47]

Participants donned a heart rate monitor (#FT1, Polar Electro, Inc, Lake Success, NY) and self-inserted a rectal thermistor 15 cm past the anal sphincter (#401, Advanced Industrial Systems; Prospect, KY paired to Alpha Technics 5000 thermometer, TE Connectivity, Berwyn, PA).[41] Then, they dressed in an Army Combat Uniform.[48] This uniform included undergarments (sports bras also for females), shorts, socks, t-shirt, pants, long-sleeve jacket, and hard helmet.

They entered an environmental chamber (Cantrol International Inc, Canada) and stood on a treadmill for 10 minutes to acclimate to the heat (~37°C, ~40% relative humidity, 25.5°C WBGT). The environmental parameters in this study (Table 2) met the military's 'white heat flag' status indicating no heat-related modification to training or the uniform was necessary.[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 with a 9.1-kg plate weight in it to simulate the weight of equipment carried in the field. They self-selected a treadmill incline and speed they felt was 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 parameters and timing of effort could be performed on the second day of testing.

When T_{REC} was ~39°C during exercise, we stirred the coolers and recorded the temperature in the middle of the coolers. Upon reaching a T_{REC} of ~39.4°C, participants rated thermal sensation and completed a second ESQ. T_{REC} was recorded every 5 minutes but monitored continuously to determine when they reached 39.5°C. No fluids were given to participants at any time during exercise to expedite the rise in 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 criteria occurred: participants reported being too tired to continue the exercise protocol before reaching the target temperature of 39.5°C, they reported or displayed severe heat illness signs or symptoms (e.g., gross unsteadiness), the lead researcher felt 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. Shorts, undergarments (including sports bra), and socks remained donned during cooling. Then, participants completed one of two interventions. For PLP, we followed manufacturer recommendations for use (Polar Products Inc, Stow, OH).[42] They lay inside PLP and, if necessary, we folded the end of the unit closest to the participants feet to minimize water accumulation at the end of the unit. We carefully poured 151.4 L (40 gal) of ~4°C water into the PLP, closed the zipper, and secured the straps on the device (Figure 1A). This process took approximately 1.5 minutes. 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 we could record water temperature 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 United States military's guidelines.[32, 33] Four bed sheets were soaked continuously in ~1°C ice water while participants exercised. When T_{REC} were ~39.48°C, we took one bed sheet from a cooler and spread it over an oversized canvas cot (#BD-82701; 214.1 cm [L] x 106.4 cm [W] x 50.0 cm [H]; Ever Advanced, Dusseldorf, Germany; Figure 1B).

Participants only lay on this cot during ISC days to ensure they were not laying in a pool of water during cooling. The cot was made out of a porous canvas with multiple holes drilled into it to allow water to drain from underneath the subject. This was done based on the assumption the ground would absorb any water lost in the transfer of the sheets from coolers to the victim in the field.

When T_{REC} were 39.5°C, participants stopped the treadmill, removed all the same clothes as PLP, and lay on the cot/first bed sheet. The other three bed sheets were removed from the coolers, wadded up, and placed over the subject's neck, chest/armpits, and groin.[32] The sides of the first sheet were then pulled over the front of the subject thereby covering the other three sheets. The sheets over the neck, groin, and chest were removed every 3.25 minutes, re-immersed in the coolers for 0.5 minutes, and then re-applied in their former spots by every 4th minute of cooling. This ice sheet "recharge" process continued until T_{REC} was 38°C.

T_{REC} was recorded every 30 seconds during cooling on both days. A stopwatch was started the moment the water was first poured on top of participants (PLP) or participants lay on the first ice sheet (ISC). Participants were asked to self-report any shivering during treatment and we recorded the time of shivering onset (if reported). Approximately half-way through cooling (T_{REC}=38.75°C), participants reported thermal sensation a third time and we re-measured cooler water temperature (ISC) or water temperature in the PLP. Once T_{REC} was 38°C, participants were removed from PLP or ISC, dried their chests, arms, and legs, and sat in the environmental chamber for 10 minutes. T_{REC} was measured every 5 minutes during recovery. During this time, they completed a third ESQ and reported thermal sensation a fourth time. After this recovery period, they removed the rectal thermistor, disrobed completely, towel dried as best as possible, and were weighed nude a second time. Then, they were excused. Participants completed their second testing day at approximately the same time of day (±2 hours) and at least 72 hours after the 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 calculated cooling rates for each half of cooling since cooling rates tend to differ over the course of treatment.[49] Means and standard deviations 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, percent hypohydration, and exercise durations since data were normally distributed. Wilcoxon signed-rank test for differences in medians were used for T_{REC} nadir and the second half of treatment cooling rates since these data were not normally distributed.

Separate repeated measures ANOVA examined 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 analyzed the data with a repeated measures ANOVA. Sphericity was assessed with Mauchly's test. Geisser-Greenhouse adjustments to *P*-values and degrees of freedom were made if the sphericity condition was violated. Upon significant interactions or main level effects, Tukey-Kramer post-hoc tests identified differences between cooling methods at each time point. Significance was accepted when $P<0.05$ (Number Cruncher Statistical Software v.2007, Kaysville, UT).

RESULTS

Participants self-reported compliance with pre-testing instructions and were similarly euhydrated as indicated by urine specific gravity (t_{13}=0.14, *P*=0.89, Table 2). They exercised in similar ambient temperatures (t_{13}=0.6, *P*=0.56), but environmental chamber relative humidity (t_{13}=2.9, *P*=0.01) and WBGT (t_{13}=3.7, *P*=0.002) were slightly higher for ISC (Table 2). All completed participants marched for similar durations (t_{13}=0.9, *P*=0.38) utilizing similar treadmill speeds and inclines and achieved a T_{REC} of 39.5°C (Table 2). Sweat rates (t_{13}=0.6, *P*=0.57) and percent hypohydration (t_{13}=0.2, *P*=0.84) were not different between conditions indicating similar levels of hypohydration post-exercise.

T_{REC} increased similarly during exercise on each testing day and all 14 finished participants were able to achieve a T_{REC} of 39.5°C ($F_{1,14}$=0.5, *P*=0.49, Figure 2). T_{REC} in the first three minutes of cooling were comparable between conditions ($F_{1,16}$=3.0, *P*=0.10, Figure 2). However, cooling duration was significantly shorter in PLP than ISC (t_{13}=5.1, *P*<0.001). Consequently, PLP had faster aggregate cooling rates (t_{13}=5.7, *P*<0.001) and cooling rates for the first (t_{13}=3.9, *P*<0.001) and second halves of treatment (z_{13}=3.2, *P*<0.001; Table 3). T_{REC} nadir post-cooling was lower in PLP than ISC (z_{13}=3.3, *P*<0.001; Figure 2).

We observed an interaction between time and condition for ESQ scores ($F_{2,26}$=11.6, *P*<0.001, Table 4). Pre-exercise ESQ scores differed from post-exercise and post-cooling in PLP but only differed from post-exercise in ISC. ESQ scores significantly differed between conditions at post-cooling (*P*<0.05). Similarly, an interaction was observed for thermal sensation ($F_{3,39}$=17.2, *P*<0.001, Table 4). PLP thermal sensation differed from ISC half-way during cooling and post-cooling (*P*<0.05). Within each condition, pre-exercise thermal sensation was different than mid-cooling and post-cooling (*P*<0.05). Eleven participants shivered in PLP with an average self-reported onset of 3.8±1.2 minutes compared to three in ISC (12.0±2.3 min).

DISCUSSION

This is the first randomized, experimental study directly comparing the cooling efficacy of PLP to ISC. This study advances our understanding of both PLP and ISC in several ways. First, it is the only PLP or ISC study to examine cooling rates after participants ruck-marched in the heat whilst 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 due to the higher metabolic demand of muscles.[51] Cumulatively, this leads to greater difficulty thermoregulating and the individual undergoes higher thermal stress.[50] Second, our participants exercised to the highest T_{REC} (i.e., 39.5°C) of all ISC studies[25, 27, 28] performed under controlled laboratory conditions. Third, we examined perceptual indicators of health and heat stress before, during, and after body interventions. Finally, we delimited the research so similar amounts of resources (e.g., coolers, support staff) were available in each condition.

There are three main clinical observations from this study. First, PLP cooled hyperthermic individuals twice as fast as ISC despite requiring similar amounts of preparation and resources. Second, ISC cooling rates met our operational definition[22] of 'acceptable' (>0.08°C/min) whereas PLP cooling rates were 'ideal' (>0.16°C/min) for EHS patients. Finally, participants reported fewer lingering heat illness signs and symptoms and more comfortable thermal sensation scores during recovery with ISC than PLP. While 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 help patients during recovery (e.g., necessity of rewarming methods).

The observation that PLP cooling rates were 'ideal' and consistent with life-saving BAG cooling rates in real heatstroke patients[5, 29-31] is consistent with other recent literature.[16, 18] Previously, authors[16, 18] demonstrated PLP cooling rates were dependent on water temperature and volume. In two similar PLP studies utilizing a hyperthermia model,[16, 18] healthy participants exercised to a T_{REC} of 39.5°C and cooled in the PLP. When 202-211 L (54 to 56 gal) of 3.2°C, 10°C, or 15°C water was used inside the device, cooling rates were 0.28±0.09°C, 0.18±0.07°C, and 0.14±0.09°C, respectively. In this study, we utilized 151 L (40 gal) of 4.2°C water and still noted excellent cooling despite using less water in PLP than other authors.[16, 18] Consequently, it appears the ice-water temperatures were able to compensate for the lower water volume utilized 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[18] and CWI.[52] The risk of afterdrop following removal of the patient 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 effectiveness. Both interventions continued to reduce T_{REC} during recovery but nadir was ~1°C lower in PLP. Our participants' T_{REC} nadir in ISC (37.56±0.18°C) and PLP (36.59±0.65°C) were comparable to others[18, 25] who monitored body core temperature for 15 minutes post-cooling. Afterdrop and hypothermia can be minimized by continuous monitoring of T_{REC} and using higher T_{REC} stopping thresholds for treatment (e.g., 39°C). Clinicians may need to have rewarming tools (e.g., heated blankets) available following

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.

While PLP cooled at 'ideal rates,' ISC rates were significantly slower (0.11±0.05°C/min) and only met the 'acceptable' cooling threshold for EHS patients (>0.08°C/min).[22] ISC cooling rates vary in the literature and should be scrutinized by publication date since the United States military changed the ISC protocol in 2016 from one cooling sheet to the protocol utilized here. Two studies[27, 28] published before 2016, examined T_{REC} cooling rates with ice towel or ISC and reported 'unacceptable' cooling rates around 0.06°C/min. Notable differences of these studies[27, 28] from the current investigation include participants having lower T_{REC} post-exercise (38.75°C-39.25°C), wearing less clothing during exercise (workout apparel v. combat uniform), having fewer ice sheets applied to the body, utilizing different water temperatures for soaking the sheets (3-14°C),[28] and reapplying the ice sheets at different intervals (every 2[27] or 5 minutes[28]). All of these methodological differences would lower the thermal gradient and explain the slower cooling rates than those reported in this study.

After 2016, two studies[26, 53] examined the effectiveness of ISC in a clinical population suffering from EHS and exertional heat illness while one study[25] examined ISC in a laboratory environment. In the laboratory study,[25] participants clothed in normal workout apparel exercised in the heat (40°C, 30% relative humidity) to mild hyperthermia (T_{REC}=38.8±0.39°C). They underwent the most current military ISC protocol[32] but still cooled, on average at 0.068°C/min. Our ISC rates were likely higher because our participants wore combat uniforms during exercise. This would have increased skin temperature and the thermal gradient between skin and ice sheets thereby helping participants cool faster.[50] Conversely, DeGroot et al.[26] retrospectively analyzed 363 EHS patients who received ISC while *enroute* to the emergency room. Patients with T_{REC}

>39°C and <39°C had ISC cooling rates of 0.16±0.08°C and 0.03±0.04°C, respectively. When ISC was applied in conjunction with chilled saline 5 military patients with initial T_{REC} ≥40.6, all patients survived and had cooling rates between 0.075°C/min to 0.13°C/min (average=0.09±0.03).[53] The current data is consistent with these cooling rates and suggests ISC can be used successfully on EHS patients. While all the patients survived with ISC treatment,[26] it is imperative to utilize cooling strategies that reduce T_{REC} as quickly as possible to prevent the possibility of long-term disability or complications stemming from treatment delays or inadequate cooling.[54]

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

Two final considerations should be noted between treatments. First, participants felt warmer, shivered less, and self-reported less intense heat illness symptoms during and after ISC than PLP. This is consistent with prior studies[18] and can likely be explained by the slower rate of cooling of ISC resulting in more time elapsing post-exercise to resolve their exercise-induced heat illness symptoms and a slightly higher WBGT during the ISC trial. Additionally, post-treatment ESQ differences between conditions can be attributed to high 'goosebumps' scores and the summation of miscellaneous other mild symptoms with PLP. However, when 10°C-15°C water was used in the PLP, both thermal sensation and ESQ improved considerably compared to when ice water (3°C) was utilized, albeit at the expense of slower cooling rates.[16] 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, ~50% of water remained in the coolers following ISC. In comparison, the PLP has a large opening at one end where water could escape if a clinician did not act to preserve the water post-cooling. Consequently, it is possible ISC could be used for >1 EHS patient while care would be needed to ensure the water remained in the PLP for subsequent EHS patients. 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 (e.g., jacket, belt, pants, helmet) to ensure consistency between participants. Second, we only utilized four coolers filled with ice and water on PLP trials. The PLP holds up to 227.1 L (60 gal) of water and the manufacturer[42] advises having 6 coolers available in the event of a heat illness. We intentionally delimited this study to four coolers so similar amounts of resources would be used each testing day. Faster PLP cooling rates than those reported in this study were observed when larger water volumes were utilized.[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 PLP. Fourth, the ice and water volume inside each cooler decreased and varied as we transferred ice sheets between the subject and coolers during treatment. The 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). Since the water temperature inside the coolers remained ≤1.7°C for the duration of testing and >50% of the cooler water volume remained after testing, we are confident the ice sheets were re-cooled effectively during the 30-second re-submersion periods. Fifth, rather than duplicate the same water temperatures for each condition, we opted for a more externally valid test by following military[32, 33] and expert[9] guidance for ISC and cold-water immersion. Consequently, the water temperatures between conditions differed by ~3°C. However, both conditions, as evidenced by our cooling rates, provided a thermal gradient encouraging cooling and provide valid data for how these tools are being utilized in the field. Sixth, we utilized the McDermott et al.[22] recommended cooling rate thresholds to clinically interpret the effectiveness of the cooling rates in our study. Other authors[20, 21] have indicated "adequate" or "insufficient" cooling rate thresholds above or below a single cut-off point of 0.15°C/min, respectively. Since PLP cooling rates were well above all of these thresholds, the only potential discrepancy in our study's interpretation surrounds the effectiveness of ISC. Given the survival of several EHS patients when treated with ISC,[26, 53] we believe ISC can be used to save EHS patients when CWI is unavailable or prohibited. However, more research is needed to determine what is considered a minimally acceptable or 'ideal' cooling rate for EHS and whether cooling rate alone and/or other criteria (e.g., morbidity, mortality, patient perceptions) should be used to describe a modality as 'ideal' or 'adequate.' Finally, our participants did not experience EHS. This is a safety limitation of all university-based laboratory studies. However, our participants had either higher or similar T_{REC} as other ISC studies[25-27] and reported signs and symptoms of heat illness and being 'very hot' prior to treatment. Regardless, much of the research investigating the effectiveness of cooling modalities utilize an exercise-induced hyperthermia model rather than EHS. Clinicians should continue to use their clinical judgment when treating EHS and applying information from hyperthermia studies to their clinical practice.

In conclusion, PLP cooled hyperthermic participants 55% faster than ISC and was the only cooling intervention to meet the 'ideal' cooling rate threshold[22] that is consistent with EHS survival and the best patient-related outcomes (e.g., survival rates, less internal organ damage, and fewer neurologic sequelae at discharge).[5, 23, 30] Since ice is difficult to maintain in the field and both interventions required the same number of coolers and support staff for implementation, PLP should be utilized over ISC in the military arena when EHS is suspected. Future research should investigate whether there is a minimal water volume to maintain PLP 'ideal cooling rate' and whether the water in a PLP can be salvaged to treat multiple victims as this remains one of the major advantages of ISC.

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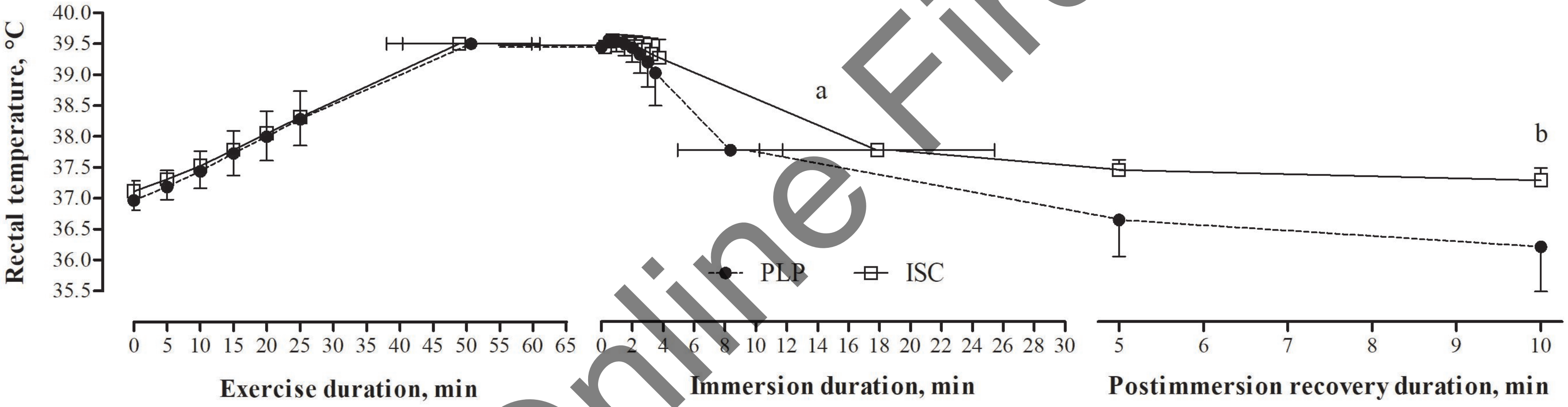
Figure Legends

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

Figure 2. 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. [a] = PLP cooling duration < ISC cooling duration (t_{13}=5.1, P<0.001). [b] = PLP nadir < ISC nadir (z_{13}, P<0.001).

A

B



Rectal temperature, °C
40.0
39.5
39.0
38.5
38.0
37.5
37.0
36.5
36.0
35.5
a
b
PLP
ISC
0 5 10 15 20 25 30 35 40 45 50 55 60 65
Exercise duration, min
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Immersion duration, min
5 6 7 8 9 10
Postimmersion recovery duration, min

Table 1. Subject demographics

Age (y)	23 ± 3
Men and women (n)	10 and 4
Height (cm)	168.5 ± 7.8
Body mass index	26 ± 5
Body density (g/cc)	1.07 ± 0.01
Body fat (%)	13 ± 6
Body surface area (m^2)	1.83 ± 0.24

Data are means ± SD. Fifteen subjects completed BAG (11 men, 4 women) and 14 completed ISC.

Table 2. Exercise, cooling, and environmental parameters between PLP and ISC

	PLP	ISC
Exercise Parameters		
Exercise duration (min)	50.5 ± 9.9	48.9 ± 10.9
Treadmill incline (%) [a]	12 ± 2	12 ± 2
Treadmill speed (km/h) [a]	4.9 ± 0.3	4.9 ± 0.4
Hydration Indices		
Pre-exercise urine specific gravity	1.009 ± 0.006	1.009 ± 0.007
Body mass pre-exercise (kg) [a]	73.81 ± 17.77	73.96 ± 11.08
Body mass post-exercise (kg) [a]	72.66 ± 17.47	72.89 ± 17.81
Sweat rate (L/h)	1.09 ± 0.39	1.14 ± 0.35
Post-testing hypohydration (%)	1.5 ± 0.5	1.5 ± 0.4
Cooler Water Temperatures		
Pre-subject arrival (°C) [b]	5.03 ± 1.01	1.67 ± 0.58
End of exercise (°C) [b]	4.22 ± 0.95	0.89 ± 0.33
Subjects half-finished cooling (°C) [b]	7.73 ± 2.15	0.39 ± 0.25
Post-cooling (°C) [b]	8.73 ± 2.31	0.27 ± 0.19
Environmental Conditions		
Temperature (°C)	37.5 ± 0.3	37.6 ± 0.3
Relative humidity (%) [b]	39 ± 1	41 ± 2
WBGT (°C) [b]	25.5 ± 0.2	26.1 ± 0.5

Data are means ± SD, n=15 (Polar Life Pod, **PLP**), n=14 (Ice sheet Cooling; ISC). WBGT = wet bulb globe temperature. [a] = data reported descriptively and were not statistically analyzed. [b] = significantly different between interventions ($P<0.05$).

Table 3. Cooling durations and rectal temperature cooling rates with the PLP and ISC

	PLP	ISC
Cooling Duration		
Aggregate (min)	8.4 ± 3.4 [a]	17.7 ± 7.6
1st half of treatment (min)	5.3 ± 2.2 [a]	8.9 ± 3.8
2nd half of treatment (min)	3.0 ± 1.4 [a]	8.7 ± 4.6
Cooling Rates		
Aggregate (°C/min)	0.22 ± 0.08 [a]	0.11 ± 0.05
1st half of treatment cooling rate (°C/min)	0.18 ± 0.06 [a]	0.11 ± 0.04
2nd half of treatment cooling rate (°C/min)	0.25 (0.23) [a]	0.10 (0.09)

Data are means ± SD with the exception of 2nd half of treatment cooling rates which are median and interquartile range (n=15 for PLP; n=14 for ISC). First half of treatment was the cooling rate of rectal temperature from 39.5°C to 38.75°C. Second half of treatment was the cooling rate of rectal temperature from 38.75°C to 38°C. [a] = PLP ≠ ISC (P<0.05). ISC = ice sheet cooling, PLP = Polar Life Pod.

Table 4. Summative environmental symptoms questionnaire (ESQ) and thermal sensation scores with PLP or ISC

	PLP	**ISC**
ESQ		
Pre-exercise	3 ± 4	2 ± 4
Post-exercise	20 ± 14 [a]	25 ± 16 [a]
Post-cooling	12 ± 11 [a,b]	3 ± 4
Thermal Sensation		
Pre-exercise	4.6 ± 0.7 [a]	4.5 ± 0.5 [a]
Post-exercise	6.7 ± 0.9	6.9 ± 0.8
Mid-cooling	1.5 ± 0.8 [a, b]	3.3 ± 0.9 [a]
Post-cooling	2.5 ± 0.6 [a, b]	3.4 ± 0.6 [a]

Data are means ± SD (n=15 for PLP; n=14 for ISC). The 16-item ESQ is rated on a 5-point Likert scale with scores ranging from 0 (not at all) to 5 (extreme). Thermal sensation is a rated on a 9-point scale with scores ranging from 0 (unbearably cold) to 9 (unbearably hot). The middle of the scale, 4, is 'comfortable.' ISC = ice sheet cooling, PLP = Polar Life Pod. [a] = different from pre-exercise within each condition, [b] = PLP ≠ ISC. All suprascripts indicate significance at P<0.05.