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14. ABSTRACT
This report provides a brief review of thermal manikin studies that were completed to estimate the cooling efficacy of commercially available products for the treatment of heat stroke. The US Army Training and Doctrine Command (TRADOC) Heat Injury Prevention Subcommittee (HIPS) asked the US Army Research Institute of Environmental Medicine (USARIEM) to study the efficacy of various methods of rapidly cooling overheated personnel as part their efforts to minimize risk associated with rigorous training. This project was conducted by USARIEM researchers in two steps. The first study, discussed in the present report, was conducted using an automated heated and sweating thermal manikin (TM). We used the TM model to quantify the efficacy of heat removal using iced bed sheets, and compared this heat removal with that of two commercially available products. For the purpose of the present report, we will quantify cooling as the process of heat removal (in Watts) from the TM. The second study, conducted in human subjects, followed up on the TM heat removal data and will be presented in a separate report.

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BACKGROUND

Despite extensive work by researchers, clinicians and unit leaders to minimize risk of heat illness, U.S. Armed Forces still experience nearly 2,500 cases of heat injury and more than 400 cases of heat stroke every year [1]. The combined effects of environmental heat stress and metabolic heat production during military training and operations can impose significant heat strain on the Warfighter. Protective clothing, such as body armor, worn during training and combat can further restrict heat loss, and increase heat production by increasing the amount of work via increased load. Without sufficient heat dissipation, hyperthermia (high body core and skin temperatures) can threaten mission success by impairing work/task performance and increasing the risk of exertional heat illness.

Extensive heat-risk mitigation procedures such as heat acclimatization, work-rest cycles, and proper hydration have been widely published [2-4]. While these procedures assist in mitigating heat strain, auxiliary cooling strategies are often warranted to maximize heat strain reduction, maintain task/work performance, and protect the health of the Warfighter. The benefits and limitations of both preventive field-cooling strategies (e.g., showers, water misting, arm immersion cooling) and field treatment methods (ice packs, fanning) are difficult to summarize given differences in circumstances surrounding their use such as weather, water temperatures, level of hyperthermia being treated, application methods/techniques, and lack of rigorous controls [4-7]. Furthermore, there is inconsistency in how guidance is applied [1]. For these reasons, it is imperative that methods for preventing and treating hyperthermia in the field be carefully described and their efficacy quantified. For the present study, our goal is to evaluate and quantify the efficacy of iced bedsheets applied using standard procedure (1) compared to 2 commercially available cooling systems: the CAERvest Core Body Cooling Vest [8] and the Polar Skin Comprehensive Cooling System [9].

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EXECUTIVE SUMMARY

Hot environments continue to be a significant threat to medical readiness and performance/ lethality of Warfighters in both training and battlefield environments. Since mission conditions often involve high ambient temperatures, the training environment must include hot environments as well. As such, the Army and other Services accept a certain level of risk of environmental/ exertional heat illness in their trainees and deployed Soldiers. In case of suspected heat illness, several methods of rapid cooling have been identified which mitigate the risk of more severe injury. One of the most common of these is the application of iced bed sheet cooling methodology.

The US Army Training and Doctrine Command (TRADOC) Heat Injury Prevention Subcommittee (HIPS) asked the US Army Research Institute of Environmental Medicine (USARIEM) to study the efficacy of various methods of rapidly cooling overheated personnel as part their efforts to minimize risk associated with rigorous training. This project was conducted by USARIEM researchers in two steps. The first study, discussed in the present report, was conducted using an automated heated and sweating thermal manikin (TM). We used the TM model to quantify the efficacy of heat removal using iced bed sheets, and compared this heat removal with that of two commercially available products. For the purpose of the present report, we will quantify cooling as the process of heat removal (in Watts) from the TM. The second study, conducted in human subjects, followed up on the TM heat removal data and will be presented in a separate report.

INTRODUCTION

Hot environments continue to be a significant threat to medical readiness and performance of Warfighters in both training and mission environments. Since mission conditions often involve high ambient temperatures, the training environment must include hot environments as well. The Army and other armed services accept a certain level of risk of environmental/ exertional heat illness in their trainees and deployed Soldiers.

Military readiness depends on rigorous military training; however, intense training can lead to exertional heat illnesses (EHI). The medical costs and long-term implications of EHI can force lost training days, impacting unit readiness and individual careers [10]. Prior to 2015, on average, more than 1,000 Soldiers developed a heat-related illness that required medical attention and/or lost duty time [1]. There were 1,210 documented heat illnesses in Soldiers during US Army Basic Combat Training (BCT) from 2014-2018 [11]. The rates varied among sites with an overall rate of 3.6 cases per 10,000 BCT person-weeks [11]. Though avoiding heat related exertional incidents remains challenging, several methods of rapid cooling have been identified which may mitigate the risk of more severe heat injury or death [12]. One of the most common of these is the application of ice sheet cooling methodology.

The US Army Training and Doctrine Command (TRADOC) Heat Injury Prevention Subcommittee (HIPS) asked USARIEM to study the efficacy of various methods of rapidly cooling overheated personnel as part their efforts to minimize risk associated with rigorous training. Specifically, we evaluated two commercially available products (the CAERvest Core Body Cooling Vest [8] and the Polar Skin Comprehensive Cooling System [9] and the current standard approach, which involves using bed sheets soaked in ice water.

Polar Skin ice sheets come in an aluminized vacuum packed bag that needs to be kept frozen before use. These sheets can be used alone or with the optional Polar Skin Ice Packs pouches. The optional Polar Skin pouches, which also need to be frozen before use, can be used when additional body cooling is required. Both the Polar Skin ice sheet and pouches are one time use. We tested the Polar Skin sheets alone, with the optional ice pouches, and placed two Polar Skin sheets over the TM. We used the medium sized Polar Skin sheet which covered the top of the torso from the neck to the upper thighs on the TM.

Similarly, the CAERvest is a flexible vest filled with a chemical that gets cold when mixed with water. This vest is also one-time use, but does not require refrigeration. When needed, the CAERvest can activated by filling it with tap water through a quick connect port using the provided water bottle. This vest covers the front and back of the torso.

Bed sheets soaked in ice water (also known as iced-sheet cooling) is a strategy that has been utilized for a long time in the military [3, 10]. The materials required to apply this technique are inexpensive and can be reused. The goal of the present project was to compare heat removal of these three approaches in a TM model.

METHODS

The TM work described in this report is the first part of a series of studies designed to quantify the ability of a commonly used cooling modality, referred to as “ice (or iced) sheets”, to decrease core body temperature in hyperthermic Soldiers who have been exercising in a hot environment.

Testing was performed according to ASTM F2371-16, Standard Test Method for Measuring the Heat Removal Rate of Personal Cooling Systems Using a Sweating Heated Manikin [13]. This standard specifies the duration of the test to be either when cooling drops to below 50 watts or up to a maximum of 2 hours. For these tests we left the TM run until it reached steady state conditions, a maximum coefficient of heat flux variance of less than 1.5%. Data used in this report are from 30 minutes of nude steady state immediately prior to vest applied. Data continued until all cooling was exhausted and the TM reached steady state once more.

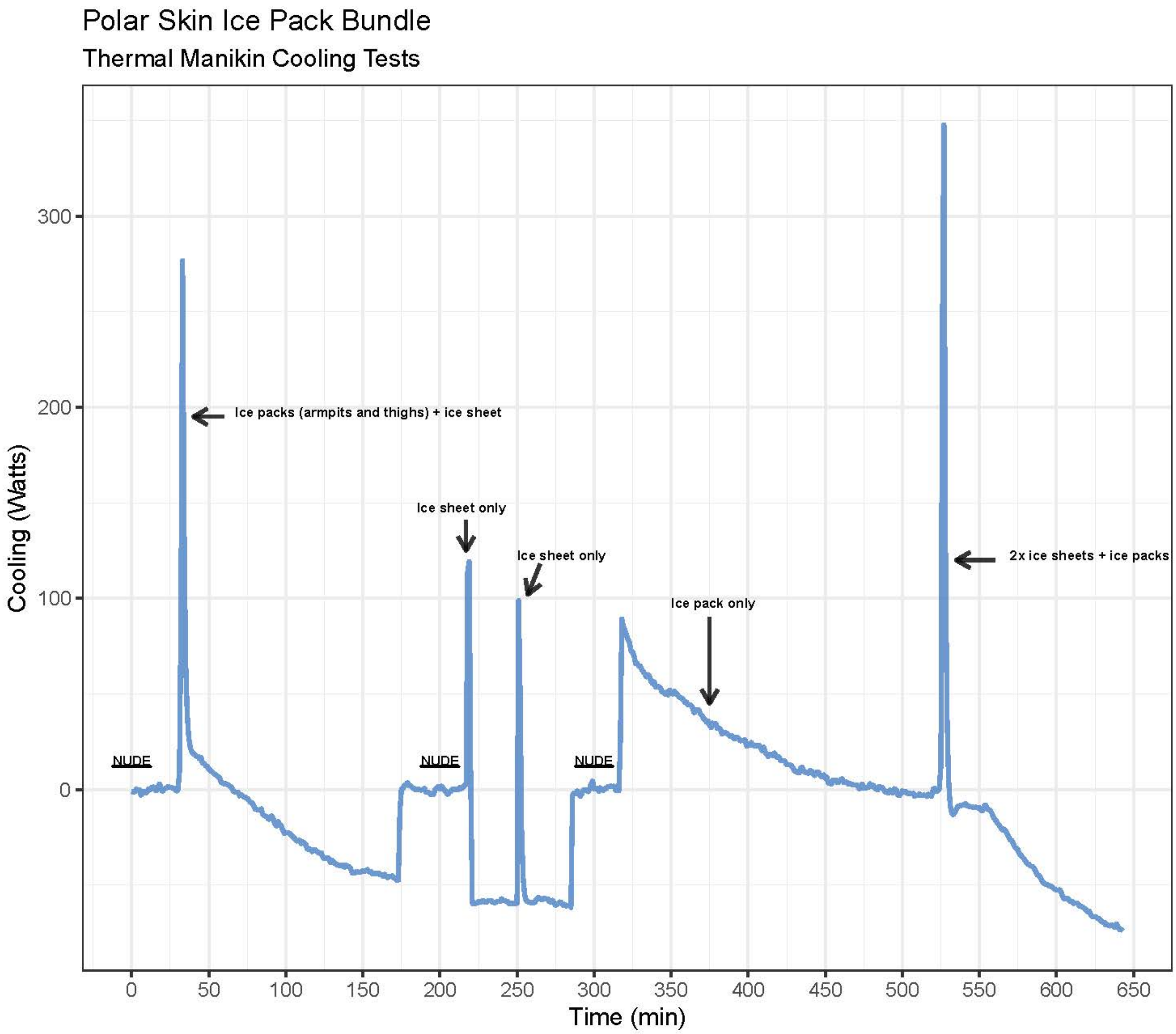
Testing was accomplished using a Measurement Technologies North West, Newton 20 zone articulated manikin [14] located in the USARIEM environmental chamber, room 232C. Total cooling power was measured according to ASTM F2371-16, Standard Test Method for Measuring the Heat Removal Rate of Personal Cooling Systems Using a Sweating Heated Manikin [13]. Environmental Chamber conditions were set at 0.4 m•s^{-1} wind speed, T_a 35°C and 40% RH for the entire test.

Heat removal (W) of iced sheets were compared with two commercial cooling products (the CAERvest Core Body Cooling Vest [8] and the Polar Skin Comprehensive Cooling System [9]). Photographs of the test set-up are shown in Appendix A.

RESULTS

Polar Ice Sheet and Packs Comparison

With the complete Polar system, ice sheet plus the four ice packs placed one under each armpit and two inside the crotch area, maximum heat removal was around 277 Watts which quickly dropped below 50 Watts in 2 minutes and to 0 watts in 30 minutes (shown in Figure 1 as Watts of cooling). When testing the Polar ice sheet by itself, a maximum cooling of 120 Watts was achieved when starting from the nude state which quickly dropped to 0 Watts in 2 minutes. Testing the ice packs under the armpits and crotch area without the ice sheet resulted in 90 Watts of cooling and a much longer duration of 155 minutes. Testing the two ice sheets plus the four ice packs placed one under each armpit and two inside the crotch area, resulted in 348 Watts which quickly dropped below 50 Watts in 5 minutes.

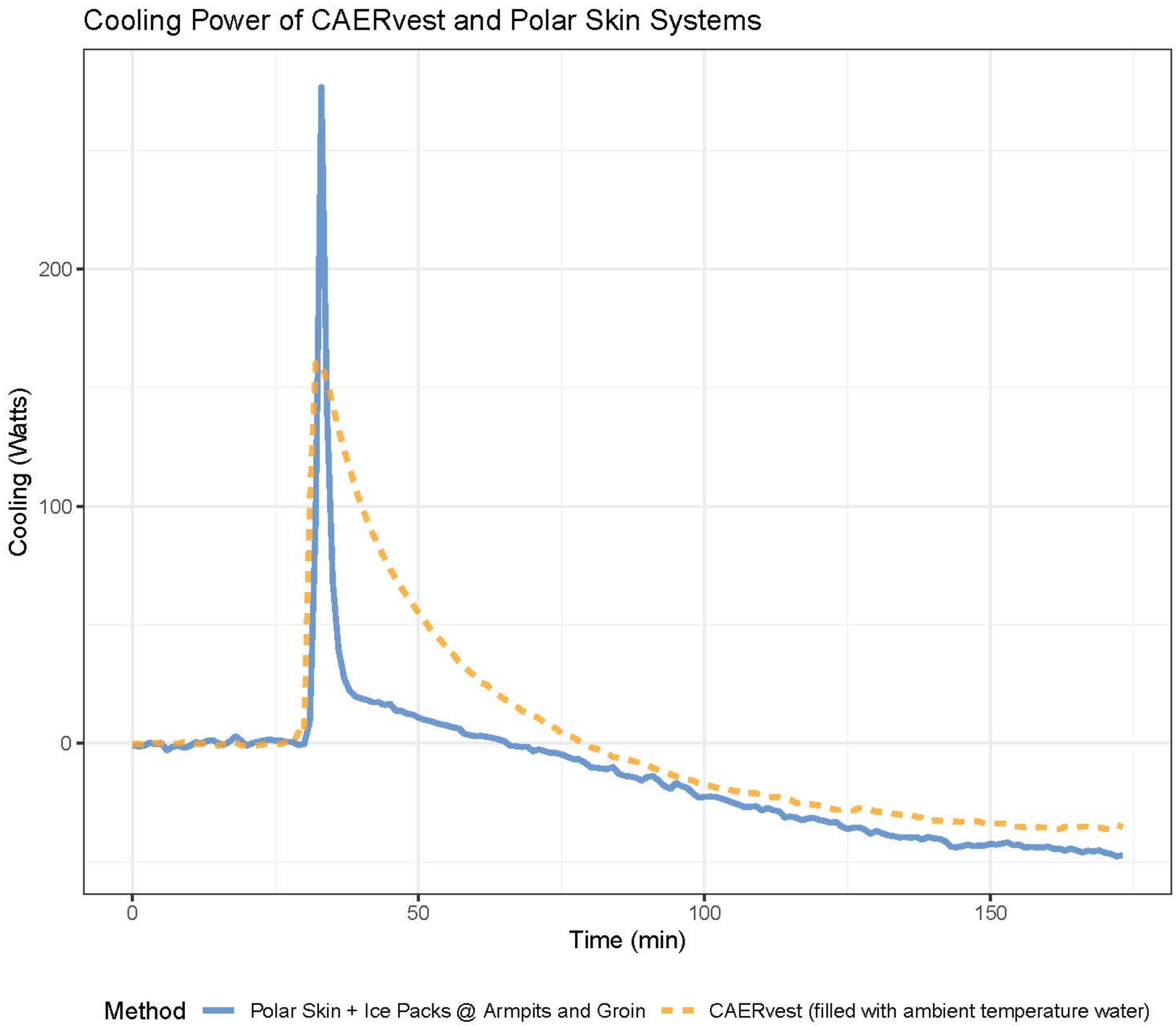


Method	Maximum Cooling	Maximum Time
Ice sheet + 4 ice packs	277 Watts	30 min
Ice sheet alone	120 Watts	2 min
Ice packs alone	120 Watts	155 min
2 ice sheets + 4 ice packs	348 Watts	5 min

Figure 1. Comparison of cooling methods (denoted as Watts of heat removal) between Polar Ice Pack Bundle and ice sheets.

CAERvest Comparison

The CAERvest was applied to the TM after 30 minutes of nude steady state data collection. Data collection continued until all heat removal was exhausted and the TM reached steady state once more (Figure 2). As shown in the figure, the CAERvest had only 38% of the peak cooling of the Polar Skin system. While the total cooling time (total time of net heat removal from the TM) was longer with the CAERvest, the peak cooling was half that of the Polar ice sheets.

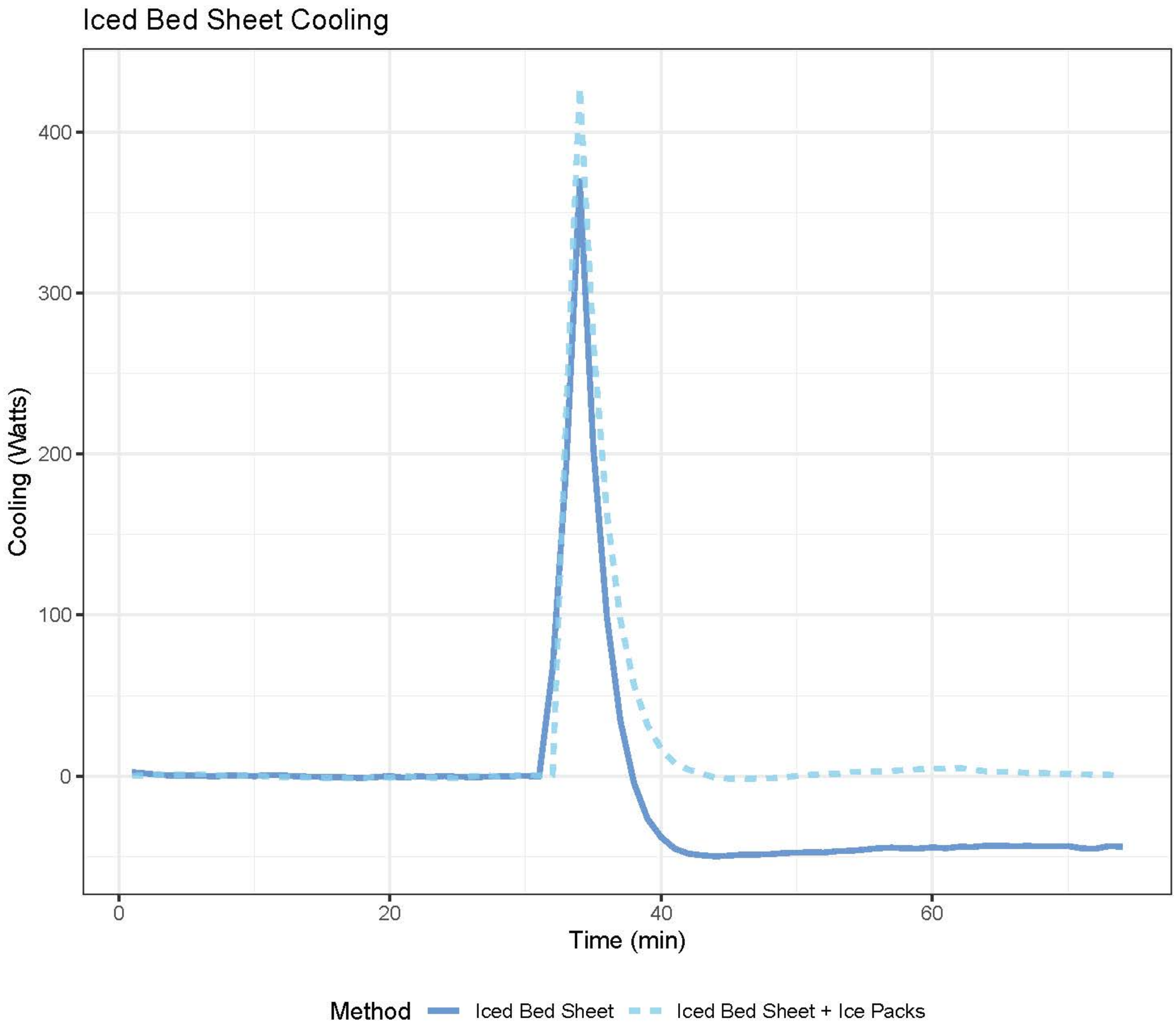


Method	Maximum Cooling	Maximum Time	Mean Cooling
CAERvest	163 Watts	48 min	55 Watts
Polar Skin + Ice Packs	277 Watts	30 min	27 Watts

Figure 2. Comparison of cooling in TM (W of heat removal) between CAERvest and Polar ice sheets with ice packs.

Iced Bed Sheets and Ice Packs

A single standard issue cotton twin size bed sheet folded in half lengthwise was soaked in ice water and placed on the manikin. These iced sheets were applied to the TM after 30 minutes of nude steady state. Iced sheets were effective at producing peak cooling of 369 Watts (see Figure 3). Furthermore, iced sheets with ice packs increased the peak cooling to 427 Watts. Both methods (iced sheets with and without iced packs) had maximal cooling times of 6 and 12 minutes, respectively, and had their maximal cooling capacity reduced by more than 50% within 3 minutes of being applied.



Method	Maximum Cooling	Maximum Time	Mean Cooling
Iced Bed Sheet	369 Watts	6 min	161 Watts
Iced Bed Sheet + Ice Packs	427 Watts	12 min	108 Watts

Figure 3. Comparison of iced bed sheets and iced bed sheets with ice packs at the groin and between armpits.

DISCUSSION

Data from the TM indicated that iced sheets provide significant heat removal. Of the two commercially available products, only the Polar Skin system provided heat removal that was comparable to the iced sheets. The CAERvest did not perform as well when rapid cooling was required. The addition of Polar Skin ice packs improved the overall maximal cooling of the iced bed sheet approach. However, ice sheet cooling diminished rapidly after being applied to the manikin; within 3 minutes, cooling was substantially diminished. Overall, a combination of iced sheets (Polar Skin or otherwise) with ice packs provided optimal heat removal.

The prognosis of an EHI patient is largely determined by how quickly the individual can be cooled [12]. In studies using TM models, the goal is to assess methods that can maximize the heat removal with the hope that this translates to a high cooling rate in hyperthermic humans. Cold water immersion stands out as the “gold standard” cooling modality and provides optimal cooling rates (> 0.14 $°C·min^{-1}$) for EHI patients [12]. However, the lack of mobility and large ice & water requirements for cold water immersion limits its feasibility in the field. Iced bed sheets, as evidenced by the present TM data, do enhance heat removal, and this likely translates to moderate cooling rate in hyperthermic humans. The heat removal of the iced sheets did rapidly diminish with time such that, in practice, sheets must be rotated at least every 3 minutes.

Our present data show that iced sheets are a cost effective and feasible method of heat removal. Although the CAERvest did not demonstrate as much heat removal as the other methods, it is the only method studied that does not require refrigeration and therefore would be appropriate for austere environments which require prolonged storage at high temperatures. CAERvest can use tap water and the Polar Skin device can be stored at 100 °F for up to 12 hours. However, both devices are only single use and must be disposed of as hazardous waste after being utilized. During training and short duration missions, where ice and water are readily available, the relative benefits of both commercially tested solutions are diminished.

Performing biophysical assessments using an automated TM in a climate controlled environment yields very repeatable results, unlike individual humans, among whom there is biological variability in responses to heat stress and to various rapid cooling methods. Contributors to this variability include anthropometrics, age, fitness, current health, medications, prior activities / heat exposure, hydration status, acclimatization status, and genetic factors. Thus it is often more expeditious to conduct the first phase of a study such as this in a TM, to provide repeatable, quantifiable results and thus identify the most important areas for follow-up work in human subjects.

CONCLUSIONS

Our present analysis shows the potential for rapid heat removal for several methodologies currently in use for mitigation of heat injury. Of the methods examined, traditional iced bed sheets and the Polar Skin device were most effective for rapid removal of heat from the TM. The CAERvest, on the other hand, provides a viable alternative for situations in which refrigeration is not available. Iced sheets provide a low cost and feasible field treatment for EHI patients. While using iced bed sheets is not always practical for Army training and operations, particularly in austere environments, it only requires a minimum of 4 bed sheets and 10 gallons of ice and water which is feasible many training and short duration mission scenarios.

In our subsequent human studies (FY 2020-2021), we evaluated the cooling potential in terms of body temperature changes in humans who were hyperthermic from exercise and heat exposure. These data will be presented in detail in a separate report, and show that iced bed sheets significantly improves the cooling rate compared to providing no active cooling treatment. However, the cooling rate provided by iced sheets is moderate (0.066 $°C \cdot min^{-1}$), and more aggressive cooling modalities (i.e., cold water immersion) should be used if available.

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APPENDIX A

Photographs of Thermal Manikin Test Methods

Figure 1. Thermal manikin without supplemental cooling

Figure 2. Thermal manikin with Polar ice sheet and ice packs

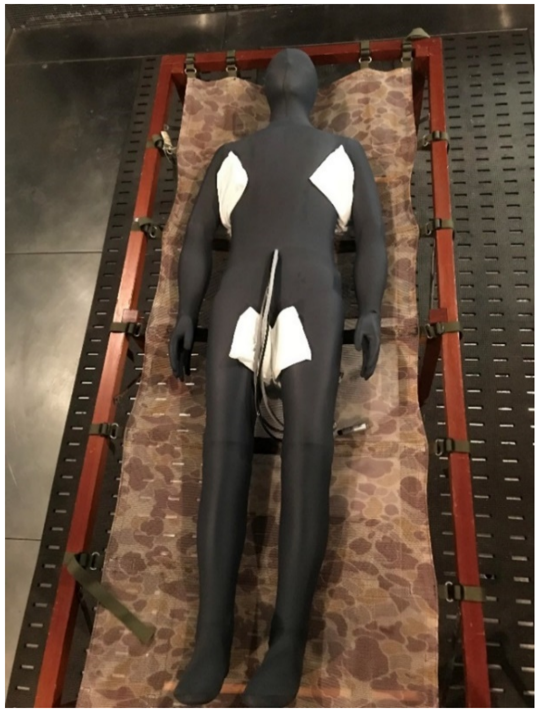

Figure 3. Thermal manikin with Polar ice packs only

Figure 4. Thermal manikin laying on the cot with two Polar ice sheets and four Polar ice packs.

Figure 5. Thermal manikin with the CAERvest core body cooling system.

Figure 6. Thermal manikin with iced sheet (bed sheet that had been soaked in ice water and folded in half lengthwise before placing on manikin)