Tarp-assisted cooling as a method of whole body cooling in hyperthermic individuals

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Abstract:

Study objective: We investigated the efficacy of tarp-assisted cooling as a body cooling modality. **Methods:** Participants exercised on a motorized treadmill in hot conditions (ambient temperature 39.5°C [103.1°F], SD 3.1°C [5.58°F]; relative humidity 38.1% [SD 6.7%]) until they reached exercise-induced hyperthermia. After exercise, participants were cooled with either partial immersion using a tarp-assisted cooling method (water temperature 9.20°C [48.56°F], SD 2.81°C [5.06°F]) or passive cooling in a climatic chamber. **Results:** There were no differences in exercise duration (mean difference=0.10 minutes; 95% CI –5.98 to 6.17 minutes or end exercise rectal temperature (mean difference=0.10°C [0.18°F]; 95% CI –0.05°C to 0.25°C [–0.09°F to 0.45°F] between tarp-assisted cooling (48.47 minutes [SD 8.27 minutes]; rectal temperature 39.73°C [103.51°F], SD 0.27°C [0.49°F]) and passive cooling (48.37 minutes [SD 7.10 minutes]; 39.63°C [103.33°F], SD 0.40°C [0.72°F]). Cooling time to rectal temperature 38.25°C (100.85°F) was significantly faster in tarp-assisted cooling (10.30 minutes [SD 1.33 minutes]) than passive cooling (42.78 [SD 5.87 minutes]). Cooling rates for tarp-assisted cooling and passive cooling were 0.17°C/min (0.31°F/min), SD 0.07°C/min (0.13°F/min) and 0.04°C/min (0.07°F/min), SD 0.01°C/min (0.02°F/min), respectively (mean difference=0.13°C [0.23°F]; 95% CI 0.09°C to 0.17°C [0.16°F to 0.31°F]. No sex differences were observed in tarp-assisted cooling rates (men 0.17°C/min [0.31°F/min], SD 0.07°C/min [0.13°F/min]; women 0.16°C/min [0.29°F/min], SD 0.07°C/min [0.13°F/min]; mean difference=0.02°C/min [0.04°F/min]; 95% CI –0.06°C/min to 0.10°C/min [–0.11°F/min to 0.18°F/min]). Women (0.04°C/min [0.07°F/min], SD 0.01°C/min [0.02°F/min]) had greater cooling rates than men (0.03°C/min [0.05°F/min], SD 0.01°C/min [0.02°F/min]) in passive cooling, with negligible clinical effect (mean difference=0.01°C/min [0.02°F/min]; 95% CI 0.001°C/min to 0.024°C/min [0.002°F/min to 0.04°F/min]). Body mass was moderately negatively correlated with the cooling rate in passive cooling (r=–0.580) but not in tarp-assisted cooling (r=–0.206). **Conclusion:** In the absence of a stationary cooling method such as cold-water immersion, tarp-assisted cooling can serve as an alternative, field-expedient method to provide on-site cooling with a satisfactory cooling rate.

Article:

Introduction

Background

Exertional heat stroke occurring during sport or physical activity is a medical emergency requiring prompt treatment for survival. It occurs when body heat production continuously exceeds the rate of heat dissipation, resulting in a rectal temperature (T_{RE}) greater than or equal to 40.5°C (104.9°F), with central nervous system dysfunction.[1] During exertional heat stroke, the failure of the thermoregulatory system causes body temperature to exceed the critical threshold for cell damage (40.83°C [105.5°F]), resulting in a cascade of events leading to endotoxemia and multiorgan dysfunction if not corrected in a timely manner.[2, 3, 4] Minimizing the time that body temperature is above this critical threshold enhances survival and reduces the risk of long-lasting sequelae.[5, 6]

Current best practices state that immediate, on-site cooling of exertional heat stroke patients before transport ("cool first, transport second") enhances the chances of survival.[1, 7, 8] Furthermore, the method of cooling that is considered the criterion standard for exertional heat stroke treatment is cold-water immersion because it provides the greatest body cooling rates (0.15°C/min to ≈0.35°C/min [0.27°F/min to ≈0.63°F/min]).[9, 10, 11]

Importance

In certain situations (ie, forward deployment in a military setting or physical labor in a remote setting), cold-water immersion may not be feasible because of spatial, facility, or financial limitations, prompting investigations into alternative methods that provide adequate cooling rates (≥0.155°C/min [0.28°F/min]) to provide proper care.[12, 13, 14]

An alternative method of body cooling is tarp-assisted cooling, which requires only a large sheet of waterproof fabric (ie, a tarp or tarpaulin), water, and ice.[15] For application of the tarp-assisted cooling method, 3 or more persons hold the tarp to create a semirecumbent position for the patient who is lying supine on the tarp. Water and ice are poured over the patient, which allows partial body ice water immersion (Figure 1). During cooling, the persons who are holding the tarp oscillate the water to maximize the effect of cooling through the convective and conductive properties of water.[16] To our knowledge, only 1 study to date has investigated the use of the tarp-assisted cooling method in a laboratory setting, in which the participants sat in semirecumbent position on a tarp and were immersed in 40 gallons of 2.1°C [35.78°F], SD 0.8°C [1.44°F] water that was continuously oscillated by researchers.[15] This study resulted in a cooling rate of 0.14°C/min [0.25°F/min], SD 0.05°C/min [0.09/min]; however, the effectiveness of tarp-assisted cooling with a lesser amount of water and ice is unknown.

Figure 1. An example of the 3-person tarp-assisted cooling method.

Goals of This Investigation

As the need for an effective, field-expedient method of cooling becomes more apparent, identification of appropriate cooling modalities warrants further investigation. Therefore, the primary aim of this study was to examine the cooling rate of the tarp-assisted cooling method with limited ice and water after exercise-induced hyperthermia. The secondary aim of the study was to compare the cooling rate of tarp-assisted cooling by sex and body mass. It was hypothesized that the tarp-assisted cooling method would result in cooling rates sufficient for that suggested for exertional heat stroke treatment and that difference in sex and body would not result in a significant difference in cooling rate.

Materials and Methods

Study Design and Setting

This study used a randomized, counterbalanced, crossover design and was performed in a laboratory setting.

Selection of Participants

Eight recreationally active, healthy men (mean age 25 years [SD 4 years]; weight 86.7 kg [SD 10.5 kg]; height 181.1 cm [SD 7.4 cm]; body fat 16.5% [SD 5.2%]) and 6 women (mean age 22 years [SD 2 years]; weight 61.3 kg [SD 6.7 kg]; height 163.5 cm [SD 6.7 cm]; body fat 22.8 % [SD 4.4%]) completed this study. Individuals with chronic health problems; fever or other illness at testing; history of cardiovascular, metabolic, or respiratory disease; history of exertional heat stroke; and musculoskeletal injury that limited physical activity were excluded from the study. All participants provided written informed consent to participate in this study, which was approved by the institutional review board at the University of Connecticut.

Interventions and Methods of Measurement

Participants were asked to come to the laboratory on 3 occasions; they completed a familiarization session and 2 exercise sessions. The 2 exercise sessions, completed in a counterbalanced order, differed according to the cooling modality used in the study; participants were cooled with either the tarp-assisted cooling method or passive cooling. Baseline nude body mass and body fat percentage with 3-site skin folds were measured during the familiarization session. The 2 exercise sessions were scheduled at least 24 hours apart from each other to allow body temperature and hydration status to return to baseline values. To control for and to standardize the thermoregulatory effect of the menstrual cycle, all female participants were tested during the luteal phase of their menstrual cycle, which was based on their self-reported menstrual history.

All exercise and cooling sessions were conducted in a climatic chamber (Model 200; Minus-Eleven, Weymouth, MA) with the following environmental conditions: ambient temperature 39.5°C [103.1°F], SD 3.1°C [5.6°F], relative humidity 38.1% (SD 6.7%), and wet bulb globe temperature 31.7°C [89.1°F], SD 3.0°C [5.4°F]. All participants were instructed to drink 500 mL of water the night before and the morning of their scheduled exercise session to ensure a state of euhydration. Urine specific gravity assessment was used to assess hydration status, with less than or equal to 1.020 as a threshold for euhydration. Pre- and postexperiment nude body mass measurement was also used to evaluate fluid loss from exercise. Water intake was restricted during exercise in both sessions. Before entering the climatic chamber, participants inserted a rectal thermometer (Model 401; Measurement Specialties, Hampton, VA) 10 cm beyond the anal sphincter to continuously monitor T_{RE} throughout the exercise and cooling portions of each exercise session. Participants also donned a pulse rate monitor (Race Trainer; Timex Group USA, Middlebury, CT) throughout exercise to ensure their exercise intensity was within test termination criteria.

Participants then entered the climatic chamber, where they sat for 10 minutes to equilibrate to the environmental conditions. They wore a short-sleeved T-shirt, running shorts, socks, and sneakers for both exercise sessions. Women additionally wore a sports bra. Exercise consisted of a 20-minute exercise sequence on a motorized treadmill, which included a 5-minute walk between 5.6 and 7.2 km/hour at a 5% incline, followed by a 15-minute jog between 8.9 and 12.1 km/hour at 1% incline. The exercise intensity was prearranged to ensure a period of sustained exercise that would be sufficient to induce hyperthermia in a controlled environment. Exercise occurred for up to 60 minutes. To ensure participant safety, exercise was terminated when one of the following was met: T_{RE} reaching 39.99°C (103.99°F), inability to continue exercise because of volitional fatigue, altered or uneven gait, pulse rate above age-predicted maximum pulse rate (220 beats/min−age) for 5 minutes, or 60 minutes of exercise.

After cessation of exercise, participants stepped off the treadmill, removed their shoes and T-shirt, and began the cooling portion of the session. The duration of cooling was determined by the amount of time it took for T_{RE} to reduce to 38.25°C (100.85°F). This temperature was chosen to prevent a hypothermic after drop after the cooling intervention.[16] In both cooling sessions, the time to initiate cooling from the end of the exercise session was measured. For the tarp-assisted cooling session, participants were instructed to lie supine on a 12-by-16-foot waterproof, polyethylene tarp (Blue Hawk, Mooresville, NC). The tarp was held by at least 3 researchers (1 at the participant's head and 1 on each side of the participant) to hold the tarp up

to allow the participant to be in semireclining position. Twenty gallons of water and 10 gallons of ice were poured into the tarp to immerse the participant's torso and legs in the cold ice water (water temperature 9.20°C [48.56°F], SD 2.81°C [5.06]). The researchers located on either side of the participant continuously agitated the tarp to circulate the water during the cooling bout. During the passive cooling session, participants removed their T-shirt and shoes and sat quietly in the climatic chamber for the entire duration of the cooling portion of the session.

Outcome Measures

Tarp-assisted cooling rate was calculated from the time in which water and ice were poured over the participant. Passive cooling rate was calculated from the time in which the participant sat in a chair after the cessation of exercise.

Primary Data Analysis

All statistical analyses were performed with SPSS Statistics (version 22; IBM Corporation, Armonk, NY). Paired sample t tests compared the cooling time and cooling rates between tarp-assisted cooling and passive cooling. Separate independent t tests compared cooling rates by sex. A 2-way ANOVA compared the interaction effect between the cooling method and sex on cooling rate. Pearson's correlation analysis was used to determine correlations between the body mass and the cooling rate (very weak |0 to 0.19|; weak |0.20 to 0.39|; moderate |0.40 to 0.59|; strong |0.60 to 0.79|; very strong |0.80 to 1.0|). Data are presented as mean (SD) unless otherwise specified. Mean difference and 95% confidence interval (CI) are provided where applicable. The significance level was set a priori at $P<.05$.

Results

There were no differences in exercise duration (mean difference=0.10 minutes; 95% CI –5.98 to 6.17 minutes; $P=.97$) and end exercise T_{RE} (mean difference=0.10°C [0.18°F]; 95% CI –0.05°C to 0.25°C [–0.09°F to 0.45°F]; $P=.18$) between tarp-assisted cooling (exercise duration 48.47 minutes [SD 8.27 minutes]; end exercise T_{RE} 39.73°C [103.51°F], SD 0.27°C [0.49°F]) and passive cooling (48.37 minutes [SD 7.10 minutes]; 39.63°C [103.33°F], SD 0.40°C [0.72°F]). Time to initiate cooling from the cessation of exercise was 3.4 minutes (SD 1.0 minutes) and 1.7 minutes (SD 0.8 minutes) for tarp-assisted cooling and passive cooling, respectively (mean difference=1.79 minutes; 95% CI 0.84 to 2.73 minutes; $P=.002$). There were no differences in T_{RE} at the beginning of cooling between tarp-assisted cooling (39.83°C [103.69°F], SD 0.37°C [0.67°F]) and passive cooling (39.61°C [103.30°F], SD 0.42°C [0.76°F]; mean difference=0.21°C [32.38°F]; 95% CI 0.04°C to 0.38°C [0.07°F to 0.68°F]; $P=0.2$). Cooling time was significantly less in tarp-assisted cooling (10.30 minutes [SD 1.33 minutes]) than passive cooling (42.78 minutes [SD 5.87 minutes]; mean difference=–32.67 minutes; 95% CI –45.46 to –19.88 minutes; $P<.001$) (Figure 2).
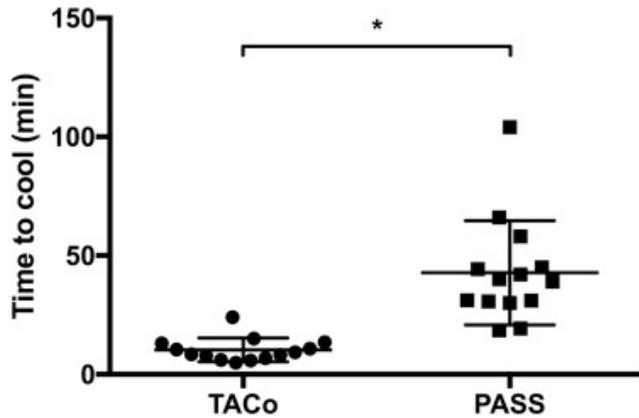
Figure 2. Cooling time to reach T_{RE} 38.25°C (100.85°F) in TACo (n=14) and PASS (mean difference=0.13°C; 95% CI 0.09°C to 0.17°C; *P*<.001). Each point represents each individual in the corresponding cooling intervention. Horizontal lines represent (n=14) the mean and SD of cooling time. *TACo*, Tarp-assisted cooling; *PASS*, passive cooling.

Cooling rates for tarp-assisted cooling and passive cooling were 0.17°C/min (0.31°F/min), SD 0.07°C/min (0.13°F/min) and 0.04°C/min (0.07°F/min), SD 0.01°C/min (0.02°F/min), respectively (mean difference=0.13°C [0.23°F]; 95% CI 0.09°C to 0.17°C [0.16°F to 0.31°F]; *P*<.001) (Figure 3). Women (0.04°C/min [0.07°F/min], SD 0.01°C/min [0.02°F/min]) had greater cooling rates than men (0.03°C/min [0.05°F/min], SD 0.01°C/min [0.02°F/min]) during passive cooling, with negligible clinical effect (mean difference=0.01°C/min [0.02°F/min]; 95% CI 0.001°C/min to 0.024°C/min [0.002°F/min to 0.04°F/min]; *P*=.03). No sex differences were observed in tarp-assisted cooling rate (men 0.17°C/min [0.31°F/min], SD 0.07°C/min [0.13°F/min]; women 0.16°C/min [0.29°F/min], SD 0.07°C/min [0.13°F/min]; *P*=.62; mean difference=0.02°C/min [0.04°F/min]; 95% CI –0.06°C/min to 0.10°C/min [–0.11°F/min to 0.18°F/min]), and no interaction was observed between cooling method and sex on cooling rate ($F_{1,26}$=0.72; *P*=.40). Body mass was moderately negatively correlated with the cooling rate in passive cooling (*r*=–0.580; *P*=.03) but only weakly negatively correlated with no statistical significance in tarp-assisted cooling (*r*=–0.206; *P*=.48).
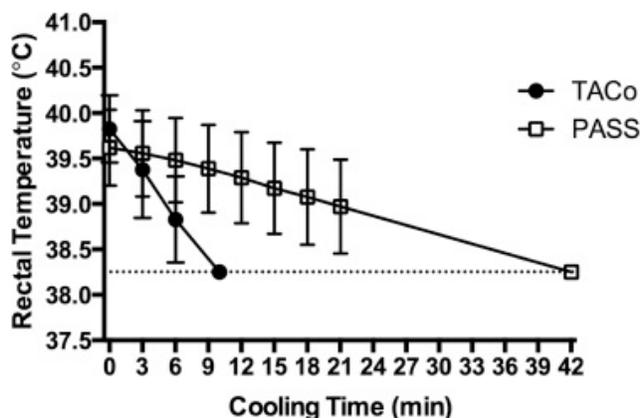

Figure 3. Mean (SD) T_{RE} during TACo and PASS. The data are represented only until the longest immersion time common to all participants. The last data point represents the average cooling time required to reach T_{RE} 38.25°C (100.85°F).

Limitations

This study was not conducted with patients with exertional heat stroke. All participants were hyperthermic by the end of the exercise session; however, they did not meet the clinical definition of exertional heat stroke (T_{RE} ≥40.5°C [104.9°F] with central nervous system dysfunction),[9] and thus the efficacy of this cooling modality in patients with thermoregulatory compromise remains unanswered. Further studies are warranted to investigate the effectiveness and feasibility of tarp-assisted cooling method in field settings (ie, outdoor medical tents, military casualties, etc) with patients with exertional heat stroke who do not have access to a cold-water immersion tub. Furthermore, the study findings may not apply to individuals who are not recreationally active.

Discussion

The purpose of our study was to examine the cooling rate of the tarp-assisted cooling method after exercise-induced hyperthermia and to compare the cooling rate by sex and body mass. Comparable cooling rates were reported in previous literature using similar water temperatures (≈8°C [≈46.4°F]) while immersing the patient to neck level in circulating water, yielding a cooling rate of 0.19°C/min (0.34°F/min), SD 0.07°C/min (0.13°F/min).[14] The small differences observed in the cooling rates between the previous study and the current study (0.17°C/min [0.31°F/min], SD 0.07°C/min [0.13°F/min]) are likely the result of total surface area immersed in water and the water temperature. The tarp-assisted cooling method used in this study used a partial body cooling in ice water (9.20°C [48.56°F], SD 2.81°C [5.06°F]) and successfully exceeded the minimal requirement in ideal cooling rate (0.155°C/min [0.28°F/min]) for treatment of exertional heat stroke.[17]

Clements et al[13] reported in their comparison between ice water immersion (5°C [41°F]) and cold water immersion (14°C [57.2°F]) that the cooling rates in the first 8 minutes of cooling were 0.18°C/min (0.32°F/min), SD 0.03°C/min (0.05°F/min) and 0.16°C/min (0.29°F/min), SD 0.01°C/min (0.02°F/min), respectively, which may indicate that water temperature may not influence the cooling rate as much as the body surface area submerged in the ice water (ie, full versus partial body immersion). The cooling rate observed in the current study was also comparable to that of previous work by Luhring et al,[15] which resulted in 0.14°C/min (0.25°F/min), SD 0.05°C/min (0.09°F/min) with 40 gallons of ice water. The difference in cooling rates between the 2 tarp-assisted cooling studies may be attributed to the different criteria for cooling termination; Luhring et al[15] stopped cooling on reaching T_{RE} 38.1°C (100.6°F) or a cooling duration of 15 minutes.

Tarp-assisted cooling was effective regardless of sex and body mass, which is similar to the results reported from the treatment of 274 patients with exertional heat stroke at the Falmouth Road Race (Falmouth, MA), where cold-water immersion provided effective cooling regardless of initial presentation T_{RE}, age, or sex.[11] In reference to individuals in our study, the participant with the largest body mass and the lowest body fat percentage (man, body mass=96.8 kg, body fat=8.9%, precool T_{RE}=39.72°C [103.50°F]) had a cooling rate of 0.20°C/min (0.36°F/min) and a total cooling time of 7.80 minutes. Conversely, the participants with the smallest body mass (woman, body mass=50.9 kg, body fat=27.0%, precool T_{RE}=39.46°C [103.03°F]) and the largest

body fat percentage in our study (woman, body mass=62.2 kg, body fat=27.9%, precool T_{RE}=39.28°C [102.70°F]) both had cooling rates of 0.09°C/min (0.16°F/min) and total cooling time of 13.5 minutes and 10.85 minutes, respectively. Although the rate was slower, the cooling time in the latter cases still falls in the acceptable cooling rate (0.078°C/min to ≈0.154°C/min [0.14°F/min to ≈0.28°F/min]) for exertional heat stroke treatment as defined by the previous literature.[17]

The average time to prepare the tarp-assisted cooling modality was 3.4 minutes (SD 1.0 minutes), with an average cooling time of 10.30 minutes (SD 1.33 minutes), which is well under the 30-minute critical time to treat patients with exertional heat stroke.[6] Furthermore, tarp-assisted cooling required only 20 gallons of water, 10 gallons of ice, and a tarp. These materials are all easy to prepare, portable, and inexpensive compared with what has been traditionally used in a full-body cold-water immersion bath with a 150-gallon tub. Unlike cooling stations (ie, cooling tubs), tarp-assisted cooling does not require a stationary location, allowing clinicians to execute cooling at the site of collapse. In addition, it required a minimum of 3 persons, which is no more than the number of persons needed to execute conventional whole-body cooling with a tub. Clinicians may also choose to lay the patient on the tarp when assessing T_{RE}, which can expedite the cooling procedure by removing the step of transferring patients to start cooling.

The current study supports the use of the tarp-assisted cooling method for body cooling within the critical treatment time for exertional heat stroke. In the absence of a stationary cooling station, such as a cold-water immersion tub, dedicated for exertional heat stroke treatment, tarp-assisted cooling can serve as an alternative, field-expedient method to provide on-site cooling with a satisfactory cooling rate.

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