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Physiologic and Perceptual Responses to Cold-Shower Cooling After Exercise-Induced Hyperthermia

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Context: Exercise conducted in hot, humid environments increases the risk for exertional heat stroke (EHS). The current recommended treatment of EHS is cold-water immersion; however, limitations may require the use of alternative resources such as a cold shower (CS) or dousing with a hose to cool EHS patients.

Objective: To investigate the cooling effectiveness of a CS after exercise-induced hyperthermia.

Design: Randomized, crossover controlled study.

Setting: Environmental chamber (temperature = 33.4°C ± 2.1°C; relative humidity = 27.1% ± 1.4%).

Patients or Other Participants: Seventeen participants (10 male, 7 female; height = 1.75 ± 0.07 m, body mass = 70.4 ± 8.7 kg, body surface area = 1.85 ± 0.13 m^2, age range = 19–35 years) volunteered.

Intervention(s): On 2 occasions, participants completed matched-intensity volitional exercise on an ergometer or treadmill to elevate rectal temperature to $\geq$39°C or until participant fatigue prevented continuation (reaching at least 38.5°C). They were then either treated with a CS (20.8°C ± 0.80°C) or seated in the chamber (control [CON] condition) for 15 minutes.

Main Outcome Measure(s): Rectal temperature, calculated cooling rate, heart rate, and perceptual measures (thermal sensation and perceived muscle pain).

Results: The rectal temperature ($P = .98$), heart rate ($P = .85$), thermal sensation ($P = .69$), and muscle pain ($P = .31$) were not different during exercise for the CS and CON trials ($P > .05$). Overall, the cooling rate was faster during CS (0.07°C/min ± 0.03°C/min) than during CON (0.04°C/min ± 0.03°C/min; $t_{16} = 2.77$, $P = .01$). Heart-rate changes were greater during CS (45 ± 20 beats per minute) compared with CON (27 ± 10 beats per minute; $t_{16} = 3.32$, $P = .004$). Thermal sensation was reduced to a greater extent with CS than with CON ($F_{3,45} = 41.12$, $P < .001$).

Conclusions: Although the CS facilitated cooling rates faster than no treatment, clinicians should continue to advocate for accepted cooling modalities and use CS only if no other validated means of cooling are available.

Key Words: heat stress, exertional heat illness, whole-body cooling, water dousing

Key Points

- The use of a cold shower to treat exertional hyperthermia was more effective than no treatment.
- The cooling rates elicited via the cold shower technique were deemed unacceptable when compared with the gold-standard treatment of cold-water immersion.
- Clinicians should continue to advocate for appropriate cold-water immersion resources. However, if cold-water immersion is not available, the cold shower technique should be used to treat patients with exertional heat illness as a last resort.

Exertional heat illness poses a severe threat to those exercising outdoors in a hot, humid environment. The most severe exertional heat illness is exertional heat stroke (EHS), characterized by a core temperature above 40°C and concomitant central nervous system dysfunction.[1–5] Early recognition and treatment of EHS yields the best possible patient outcomes.[6] Decreasing core temperature below 40°C as quickly as possible reduces the likelihood of organ damage and concomitantly increases the rate of survival.[1,4,5,7] Thus, the treatment should be initiated within 30 minutes of EHS recognition, with rates of cooling no lower than 0.1°C/min.[7] However, should cooling be delayed longer than 30 minutes, a modality that yields a cooling rate no lower than 0.15°C/min is recommended.[7] Efficient clinical management through a proper emergency action plan will provide clinicians with the preparation and guidance to successfully treat individuals with EHS.[6–8]

The current recommendation for treatment of EHS is cold-water immersion (CWI) because it has demonstrated the most rapid whole-body cooling.[4,5] Faster cooling rates have been observed with colder water and large skin-surface immersion.[1,9,10] Cooling rates of EHS patients using CWI (0.22°C/min)[5] demonstrate consistency with those reported in hyperthermic research participants (0.19°C/min).[3] Unfortunately, a large tub for CWI may not be available at all facilities due to monetary or spatial restrictions. Most athletic venues, however, have water access via a hose or an adjacent locker room with showers. Thus, a cold shower (CS) may be a viable alternative for CWI because most games and practices take place near a shower facility or at least with a water hose at the field of play. Furthermore, the use of existing resources could eliminate the monetary restrictions that often prevent optimal treatment plans from being implemented. However, alternative modalities that can effectively cool patients using available facilities require experimental testing so that evidence-based recommendations are followed in emergency planning.

Cooling also elicits additional physiologic and perceptual benefits that may occur with CS after exertional hyperthermia. DeMartini et al[11] demonstrated reduced thermal-sensation scores compared with a control (CON) trial using a variety of cooling techniques, including CWI, ice towels, and ice vests, after exertional hyperthermia. Additionally, decreases in heart rate (HR) after 10 minutes of cooling were augmented the most using CWI and ice towels.[11] As the surface area covered by these modalities is only slightly greater than with a CS, we would expect that similar HR decreases would occur with the application of CS. Further, modalities with even less coverage than CS (eg, ice vests and ice buckets) reduced thermal sensation; thus, CS should elicit similar results.

The use of CS has demonstrated varied success, with very few researchers using only CS or water dousing as the method of cooling. One such case report[12] demonstrated cooling rates as low as 0.044°C/min during continuous water splashing. Even with the addition of fanning or an intravenous fluid infusion, cooling rates varied considerably from acceptable (0.08°C/min–0.15°C/min) to unacceptable (<0.08°C/min).[3] In a single publication,[13] altering the coverage of the patient with water while fanning resulted in cooling rates ranging from 0.08°C/min to 0.27°C/min. Given these varied patient responses, continued investigation is needed.

The cooling rates of CWI alternatives must be analyzed experimentally to ensure that exertional heat illness and EHS patients are receiving the best treatment. Thus, the purpose of our study was to investigate the effectiveness of cooling using a CS after exercise-induced hyperthermia. We hypothesized that the CS would provide faster cooling than the CON condition while augmenting reductions in HR, thermal sensation, and muscle pain.

METHODS

Participants

Seventeen healthy participants (10 male, 7 female; height = 1.75 ± 0.07 m, body mass = 70.4 ± 8.7 kg, body surface area = 1.85 ± 0.13 m^2, age range = 19–35 years) volunteered for the study. Participants were physically active (at least 3 times per week for at least 30 minutes each time), had no history of chronic disease or illness, were not suffering from any injury, and had not experienced heat exhaustion or EHS in the past 3 years. Testing occurred in early fall, so participants likely were partially acclimatized. However, the trials were conducted 1 week apart; thus, acclimatization status did not change. Informed consent was obtained from all participants before the experimental procedures, which were approved by the University of Arkansas Institutional Review Board.

Pre-Exercise Protocol

All participants completed an experimental and a CON trial. Trials were conducted at least 7 days apart at approximately the same time of day (within 1 hour). Participants were instructed to avoid high-intensity exercise the day before each session and to consume 473 mL (16 oz) of water the night before and the morning of the trial to ensure euhydration when they arrived. Upon arrival, participants dressed in shorts and an exercise top (cotton/spandex bra top for women), and instrumentation was applied. Height and weight were then recorded. Participants then entered a climate-controlled room (temperature = 33.4°C ± 2.1°C; relative humidity = 27.1% ± 1.4%) to begin a 10-minute acclimation period during which baseline physiologic and perceptual measures were recorded.

Instrumentation

During exercise and treatment, rectal temperature (T_{re}) was measured via rectal thermocouple (model RET-1; Physitemp Instruments Inc, Clifton, NJ) inserted to a depth of at least 10 cm past the anal sphincter. Each participant used his or her same thermocouple for each trial to ensure reliability. The HR was recorded continuously during exercise and treatment using a cardiotachometer (model FT1/T31; Polar Inc, Lake Success, NY). Before testing, hydration status was measured via handheld refractometer (model Master-SUR/NM; Atago Co Ltd, Tokyo, Japan) to quantify urine specific gravity (USG). If participants were not hydrated upon arrival (USG $\geq$ 1.020), they were provided water until USG was $\leq$1.020. Finally, ambient temperature and percentage of humidity were measured using a portable weather station (model Anemometer Barometer Pen 850022; Sper Scientific LTD, Scottsdale, AZ).

Exercise Protocol

All participants took part in volitional exercise at a self-chosen mode, resistance, speed, and cadence. Participants exercised using a cycle ergometer or treadmill, or both; each person was allowed to choose and change the mode at any point during the testing period. Exercise mode, time, and intensity (ie, treadmill incline, speed, cycle resistance) used in the first trial were recorded and matched during the subsequent trial. Fluid intake was ad libitum during trial 1, quantified using a calibrated food scale (model Catapult 1000; OHAUS Corp, Parsippany, NJ), and matched during trial 2. Exercise was terminated after a maximum of 90 minutes, if a T_{re} of 40°C was reached, if the participant was too fatigued to continue exercising, or if signs or symptoms of heat exhaustion or EHS were exhibited. All participants exercised between 30 and 50 minutes, and no one reached 40°C or demonstrated signs of heat exhaustion or EHS. A total of 8 participants became fatigued before reaching 39°C; however, all reached at least 38.5°C.

We measured HR and T_{re} every 10 minutes during exercise. Perceptual and physiologic measures were also recorded at exercise termination. Environmental temperature and relative humidity were monitored every 15 minutes.

Local Area Water Temperatures

We assessed local clinical athletic-venue water temperatures during the 2 months before the study so we could

Table. Rectal Temperature and Heart Rate Before and After Exercise (Mean ± SD)

	Condition			
	Control		Cold Shower	
Variable	Pre-Exercise	End Exercise	Pre-Exercise	End Exercise
Rectal temperature, °C	37.15 ± 0.35	39.04 ± 0.38[a]	37.05 ± 0.36	39.09 ± 0.25[a]
Heart rate, beats per minute	83 ± 12	172 ± 16[a]	88 ± 14	174 ± 17[a]

[a] Indicates difference from pre-exercise ($P < .05$).

approximate expected CS water temperatures. On examining water temperatures of outdoor hoses (n = 5) and showers (n = 7), we found that shower temperature was 28.2°C ± 4.4°C, and hose temperature was 23.4°C ± 1.1°C. The hoses and showers were turned to the coldest possible setting.

Perceptual Measures

To document exercise stress and quantify perceptual responses to treatment, we asked questions pretreatment and posttreatment to assess thermal sensation (range, 0.5–10)[14] and muscle pain (range, 0–10)[15] using previously described methods.

Treatment Protocol

The transition period from the end of exercise to the start of treatment was standardized at 3 minutes to simulate the reasonably efficient transfer of a patient from playing field to treatment area. Participants remained in the heat chamber and sat in a comfortable upright chair for 15 minutes during the CON condition because many athletic venues do not have an air-conditioned locker room in close proximity to practice fields.

During the CS treatment, participants were transferred to a seated position within a showering area in the heated room and sprayed with a hose (flow rate of 14.2 L/min) at an average temperature of 20.8°C ± 0.80°C for 15 minutes. To create the spray, the researcher partially blocked the end of the hose with a finger to produce a wider stream for water coverage. The hose was mounted so as to direct water to the participant's head, shoulders, back, and thighs, and the spray was moved continuously (ie, not fixating on an area for more than 1–2 seconds) among these areas to maximize cold-water contact with the skin. Water temperature was monitored with a thermocouple for the duration of treatment and adjusted when necessary. Perceptual measures were recorded at the start and every 5 minutes during both conditions. The HR and T_{re} were collected at the start of treatment and every subsequent minute.

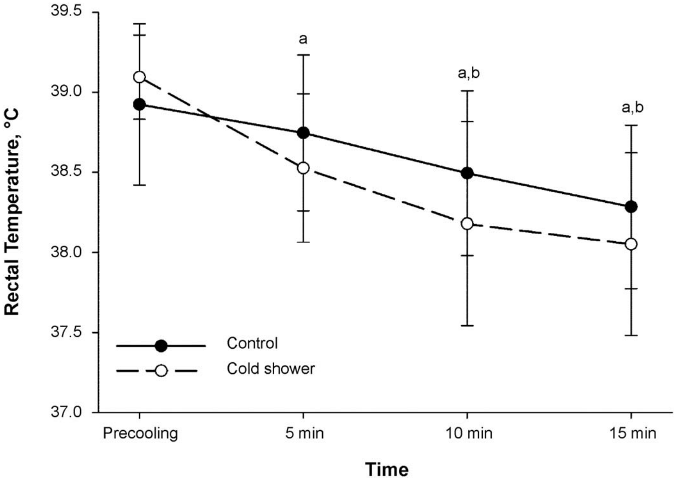

Figure 1. Rectal temperature responses to cold-shower and control conditions during 15 minutes of treatment after exercise. [a] Indicates difference from precooling ($P < .05$). [b] Indicates difference from 5 minutes ($P < .05$).

Data Analysis

We calculated cooling rates using the difference from pretreatment to posttreatment T_{re} divided by the treatment time (15 minutes). Differences in cooling rates and changes in HR were analyzed using paired *t* tests. Two-way repeated-measures analysis of variance was used to assess differences in physiologic and perceptual measures across time and between cooling methods. Bonferroni post hoc tests were conducted to identify differences at each time point between conditions. All data are presented as mean ± standard deviation. The α level was set a priori at .05.

RESULTS

Physiologic Measures

Exercise T_{re} and HR measures were not different between trials (Table). The T_{re} responses during the treatment are shown in Figure 1, including an interaction of time and treatment ($F_{3,48} = 6.60$, $P = .003$). Post hoc analysis demonstrated no differences at any time between the CS and CON treatments ($P > .05$); however, T_{re} was lower at 10 and 15 minutes than at precooling and at 5 minutes in CON, whereas in the CS trial, all time points were lower than at precooling ($P < .05$). The CS cooling rate (0.07°C/min ± 0.03°C/min) was faster than the CON cooling rate (0.04°C/min ± 0.03°C/min; $t_{16} = 2.77$, $P = .014$). Cooling rates were further broken down into 5-minute segments, which displayed an interaction of time and treatment ($F_{3,48} = 5.57$, $P = .02$). Post hoc analysis demonstrated that cooling rates were only different between CS (0.11°C/min) and CON (0.04°C/min, $P < .05$) in the first 5 minutes; there were no differences in cooling rates from 5 to 10 minutes (CS = 0.06°C/min versus CON = 0.05°C/min, $P > .05$) or 10 to 15 minutes (CS = 0.04°C/min versus CON = 0.04°C/min, $P > .05$).

We identified an interaction of time and treatment for HR ($F_{3,48} = 14.38$, $P < .001$). Post hoc analysis showed a lower HR at 5 and 10 minutes during CS compared with CON ($P < .05$; Figure 2). The CS trial elicited a greater change in HR (45 ± 20 beats per minute) from pretreatment to the end of treatment than the CON trial (27 ± 10 beats per minute; $t_{16} = 3.32$, $P = .004$).

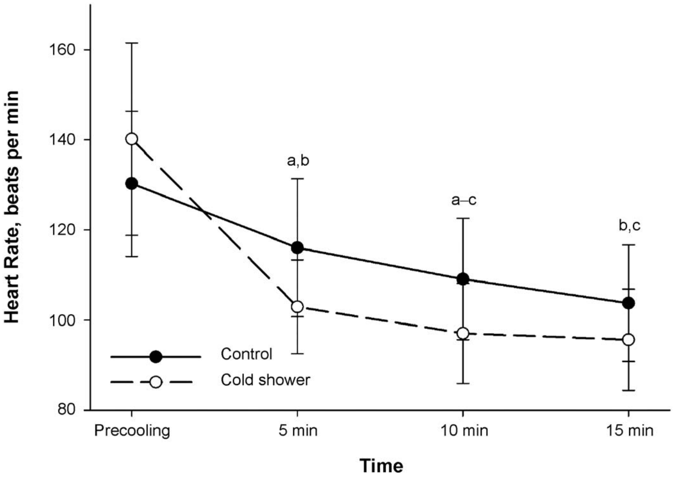

Figure 2. Heart-rate responses to cold-shower and control conditions during 15 minutes of treatment after exercise. [a] Indicates difference from control at corresponding time point ($P < .05$). [b] Indicates difference from precooling ($P < .05$). [c] Indicates difference from 5 minutes ($P < .05$).

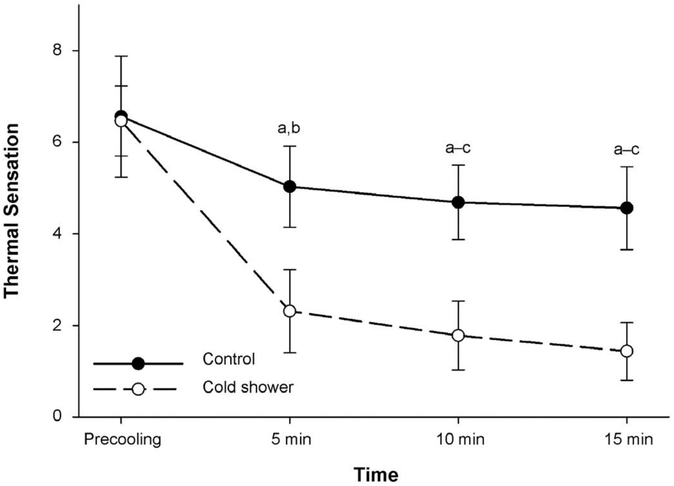

Figure 3. Thermal sensation during treatment with cold-shower and control conditions. [a] Indicates difference from control ($P < .05$). [b] Indicates difference from precooling ($P < .05$). [c] Indicates difference from 5 minutes ($P < .05$).

Perceptual Measures

The perceptual data presented are for only 16 participants, as 1 person provided incomplete data. For thermal sensation, a significant interaction of time and treatment was noted ($F_{3,45} = 41.12$, $P < .001$). The CS trial elicited a lower level of thermal sensation at 5, 10, and 15 minutes of treatment as compared with the CON trial ($P < .001$; Figure 3). For muscle pain, there was neither a main effect of time ($F_{3,45} = 1.06$, $P = .36$) nor an interaction of time and treatment ($F_{3,45} = 0.24$, $P = .75$). A main effect for treatment occurred, as muscle pain was elevated with the CS trial (0.6 ± 0.9) compared with the CON trial (0.2 ± 0.6; $F_{3,15} = 6.00$, $P = .027$).

DISCUSSION

The cooling effectiveness of the CS in the treatment of exertional hyperthermia has been investigated somewhat but not specifically in a controlled, laboratory setting.[3,12,13,16] We demonstrated that the CS treatment produced faster cooling rates than no treatment; however, the rate of cooling was slower than that produced by currently recommended techniques.[3] We analyzed temperature responses to the treatment protocols using both T_{re} throughout treatment and overall cooling rates. The rates of cooling during each protocol allowed for a more robust analysis as they incorporated changes in T_{re}, thereby reducing variability. The significant difference in the cooling rates is further explained by a slightly elevated T_{re} at the precooling time point as well as a slightly reduced T_{re} at the end of cooling in the CS protocol.

Yet the demonstrated cooling rate (0.07°C/min) would be deemed unacceptable for the effective treatment of EHS.[3] We used these cooling rates to estimate the time required to reduce an EHS patient's maximal core temperature of 42.2°C to 38.9°C; the CS condition required 60.3 ± 34.8 minutes and the CON condition required 100.7 ± 66.6 minutes.[3] Furthermore, the exponential nature of the cooling rate demonstrated that, after the first 5 minutes of treatment, the CS and CON conditions did not differ. For a patient with EHS, taking an estimated 60 minutes to reduce core temperature is dangerous. This is, however, a limitation to assume that cooling in EHS patients using CS is the same as in hyperthermic individuals. There is support for our extrapolation from laboratory to a clinical scenario, given that the average CWI cooling rates were similar to those from reports in EHS patients (0.22°C/min)[5] and hyperthermic laboratory settings (0.19°C/min).[3] It should be noted that, although the fastest possible reduction of core temperature is the goal of an effective EHS cooling treatment, the CS would still be recommended in the event that CWI was not available. Any reduction in core temperature that can be initiated while awaiting the arrival of emergency medical services may improve the chance of survival for an individual suffering from EHS. Yet the clinician's goal should always be to use the modality that cools most quickly. Thus, if a clinician currently relies solely on CS as the primary cooling modality in the institution's emergency action plan, he or she should request reconsideration and continue to advocate for validated techniques such as CWI. It may also benefit the patient to attempt to augment CS cooling using additional modalities such as ice towels and fanning.

Case reports have demonstrated variable cooling rates while dousing patients with cold water; however, many authors[3,12,13,16] also supplemented cooling with additional techniques (eg, fanning, cooled intravenous fluid infusion). Barner et al[13] found cooling rates that were slightly faster than ours from spraying participants with water and fanning them. This combination of fanning and spraying water still yielded vastly different cooling rates between the 2 patients studied (0.08°C/min and 0.27°C/min), even though both started at a T_{re} of 38.8°C.[13] The authors[13] attributed this difference to insufficient coverage of the first patient with water. Heled et al[12] doused patients with cold water and implemented intravenous infusion. This method demonstrated a cooling rate of only 0.05°C/min. Wyndham et al[16] reported nearly unacceptable cooling rates using CS alone (0.05°C/min) or combined with wind and compressed air (0.076°C/min).[3] The methods they used to calculate the cooling rates were unusual: instead of dividing the difference in core temperatures by the cooling time, they fit a straight line to a temperature and time plot for each participant at temperatures above 38.3°C. Thus, the data must be interpreted with caution as the different calculation methods may have altered the results.

The many different experimental procedures using CS may be a factor in the variable outcomes; however, an insufficient temperature gradient compared with CWI may be a key factor to its ineffectiveness. An effective EHS treatment puts the greatest possible skin surface area in contact with water and provides a temperature gradient facilitating rapid heat exchange.[9,10] Colder water temperatures (2°C) during CWI have resulted in the fastest cooling rates with a continuing afterdrop in T_{re} following removal.[9,10] When water temperatures are similar to ours (20°C), CWI facilitates much faster cooling with a rate of 0.19°C/min.[9] Thus, it is likely that the slow cooling rate of the CS in the present study (0.07°C/min) is not attributable solely to water temperature. Even temperate water (26°C), which has been suggested to reduce patient discomfort associated with colder water, provided effective cooling (0.10°C/min) during CWI, albeit at a slower rate than the cooling rates recorded with colder water.[16] It is interesting that this water temperature corresponds well with the water temperatures in the practice facilities surrounding our laboratory (26.0°C ± 4.1°C). We would expect that, in a similar pattern to CWI, the warmer water temperature in these facilities would further reduce the cooling effectiveness of CS compared with our results. Additionally, the water temperature in these facilities may change as a function of the ambient temperature. Thus, if summer heat causes the treatment water to be warmer, cooling would be slowed even further. However, although water temperature may alter cooling, the ineffectiveness of the CS technique is probably not a function of water temperature.

The ineffectiveness of CS is likely because of reductions in consistent skin surface contact with the water (ie, a sufficient water temperature but not enough coverage of the skin). Convective heat loss via cold-water contact with the skin decreases skin blood flow and limits heat exchange.[17–19] This is also true of CWI, but the larger surface area contact and constant water movement to accentuate convective heat loss augments heat transfer.[9,10,17] Therefore, the amount of surface area contacted during CS may not be large enough to offset cold-induced vasoconstriction, resulting in attenuated heat transfer and cooling.

We found greater changes in HR with the CS trial, which may have resulted from reduced skin blood flow. The cold-induced cutaneous vasoconstriction that occurs with CS probably enhanced venous return and increased central venous pressure, causing a reduction in HR.[18,19] It is noteworthy that when cooling was followed by exercise, HR remained lower, suggesting a potential recovery or performance benefit.[20]

In agreement with another study,[11] we identified perceptual decreases in thermal sensation, which suggest a patient may feel better but do not reflect a patient's overall recovery. Less thermal sensation with CS was likely driven by reductions in skin temperature that occurred with the application of cold water from the CS. The reduction in mean body temperature, which is partially determined by skin temperature, would elicit reductions in thermal sensation through feedback.[21] Combined effects of these perceptual benefits and decreased HR could be beneficial in subsequent exercise performance.[11] Furthermore, the minor elevation in muscle pain (0.6 ± 0.9) during CS, even though statistically significant, would have little clinical significance. Thus, the CS may be more applicable to strength and performance factors than to EHI treatment.

Several limitations were present in the current study. The variability in the exercise protocol likely resulted in the variability in T_{re} before treatment. The goal of the exercise protocol was to induce exertional hyperthermia; however, we did not establish a specified target T_{re}. Evidence[5] indicates that initial body temperature did not predict cooling rate; however, this analysis was conducted in patients with exertional heat illness and using analysis of variance regression and, therefore, must be interpreted with caution. The protocols were also matched between trials for each participant; thus, each participant's rate of cooling was attributed to the type of treatment received. The cooling rates elicited by CS or CON should be a consequence of the treatment and less influenced by starting T_{re}.

Another possible limitation may have been the variable ratios of body surface area to lean body mass among participants.[22] Friesen et al[22] demonstrated that a higher body surface area-to-lean body mass ratio results in faster cooling than a lower body surface area-to-lean body mass ratio. As a result, the CS technique may elicit faster cooling in those with higher body surface area-to-lean body mass ratios. Further, the variability in T_{re} reduction among participants in the present study may have been attributed to differences in body composition. However, the participants in our investigation represented a wide spectrum of recreationally active individuals, and each individual was compared with himself or herself, thereby limiting the effect of body composition when comparing one modality with another.

CONCLUSIONS

Our purpose was to examine the cooling effectiveness of a CS after exertional hyperthermia. Despite some perceptual benefit, it does not appear that the CS technique we used is a viable first-option treatment for hyperthermia. Although the CS technique cooled better than no treatment, it was not effective in reducing temperature as rapidly as previously demonstrated techniques (eg, CWI). Thus, if an emergency action plan currently relies upon CS, the clinician should strongly recommend reconsideration and continue to advocate for immersion materials. However, if CWI is not available, the use of CS while awaiting the arrival of emergency medical services is advised to begin the process of reducing a patient's core temperature as soon as possible. Further, the clinician should combine the CS with any other available means of cooling to augment core temperature reduction. At present, we recommend continuing to include CWI whenever possible for emergency treatment of patients with EHS.

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