Ice-Water Immersion and Cold-Water Immersion Provide Similar Cooling Rates in Runners With Exercise-Induced Hyperthermia

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Objective: To assess whether ice-water immersion or cold-water immersion is the more effective treatment for rapidly cooling hyperthermic runners.

Design and Setting: 17 heat-acclimated highly trained distance runners (age = 28 ± 2 years, height = 180 ± 2 cm, weight = 68.5 ± 2.1 kg, body fat = 11.2 ± 1.3%, training volume = 89 ± 10 km/wk) completed a hilly trail run (approximately 19 km and 86 minutes) in the heat (wet-bulb globe temperature = 27 ± 1°C) at an individually selected “comfortable” pace on 3 occasions 1 week apart. The random, crossover design included (1) distance run, then 12 minutes of ice-water immersion (5.15 ± 0.20°C), (2) distance run, then 12 minutes of cold-water immersion (14.03 ± 0.28°C), or (3) distance run, then 12 minutes of mock immersion (no water, air temperature = 28.88 ± 0.76°C).

Measurements: Each subject was immersed from the shoulders to the hip joints for 12 minutes in a tub. Three minutes elapsed between the distance run and the start of immersion. Rectal temperature was recorded at the start of immersion, at each minute of immersion, and 3, 6, 10, and 15 minutes post-immersion. No rehydration occurred during any trial.

Results: Length of distance run, time to complete distance run, rectal temperature, and percentage of dehydration after distance run were similar (P > .05) among all trials, as was the wet-bulb globe temperature. No differences (P > .05) for cooling rates were found when comparing ice-water immersion, cold-water immersion, and mock immersion at the start of immersion to 10 minutes, and the start of immersion to every other time point thereafter. Rectal temperatures were similar (P > .05) between ice-water immersion and cold-water immersion at the completion of immersion and 15 minutes postimmersion, but ice-water immersion rectal temperatures were less (P < .05) than cold-water immersion at 6 and 10 minutes post-immersion.

Conclusions: Cooling rates were nearly identical between ice-water immersion and cold-water immersion, while both were 38% more effective in cooling after 12 minutes of immersion than the mock-immersion trial. Given the similarities in cooling rates and rectal temperatures between ice-water immersion and cold-water immersion, either mode of cooling is recommended for treating the hyperthermic individual.

Key Words: hyperthermia, body cooling, cooling rates, exertional heat illness

Hyperthermia is common during exercise and is exaggerated when the exercise session occurs in the heat.¹ When the thermoregulatory systems are overwhelmed for a sustained period of time, hyperthermia can progress into exertional heat stroke.² Exertional heat stroke is a life-threatening condition that occurs when the accumulation of heat dramatically exceeds the body’s ability to dissipate heat.³ Factors such as dehydration, medications, illness, sleep deprivation, history of heat illness, increased body mass index, poor physical condition, alcohol and drug abuse, electrolyte imbalances, equipment and clothing, and not being acclimated may also predispose a person to having a heat stroke.⁴ Although many modes of caring for heat illnesses exist, no single treatment for patients who experience exertional heat stroke is universally accepted. What is known, however, is that the mortality rate associated with exertional heat stroke is positively correlated with the length of time it takes to cool the athlete; thus, the need for rapid cooling is strong.⁴⁻⁶
METHODS

Subjects

We recruited 17 highly trained, heat-acclimated distance runners from a college cross-country team and the local running community. Screening information was obtained to ensure that subjects met the following criteria: (1) no chronic health problems, (2) no previous history of heat illness, and (3) no history of cardiovascular, metabolic, or respiratory disease. The physical characteristics of the subjects (3 women, 14 men) were (mean ± SEM) age, 28 ± 2 years; height, 180 ± 2 cm; weight, 68.5 ± 2.1 kg; body fat, 11.2 ± 1.3%; and training volume, 89 ± 10 km/wk. The subjects were actively competing in 5-km or longer distance races.

Subjects attended a briefing meeting and signed an informed consent statement before any experimentation to ensure understanding of the testing parameters and the benefits and risks of the study. All subjects completed medical and training history questionnaires. The protocol was approved by the Institutional Review Board for Studies Involving Human Subjects. Subjects were paid for their participation in the study.

Experimental Protocol

Before each of their 3 experimental trials, subjects were provided with a preparation checklist. An investigator conducted a brief meeting after each trial to remind the subject of the proper procedures to follow for the subsequent trial. At least 1 week separated the trials. Each trial consisted of 8 discrete time components. These included arrival, a 20-minute equilibration period, baseline, two 45-minute distance runs, preimmersion, one of 3 different immersions (mock immersion, ice-water immersion, or cold-water immersion), and postimmersion (Figure 1). Wet-bulb globe temperature (WBGT) was measured at several points during each trial to gain an indication of overall environmental stress. No rehydration occurred during any trial.

Arrival. On the morning of each experimental trial, the subjects reported in a euhydrated state to an outdoor pavilion between 11:00 AM and noon. The pavilion had a roof, but all sides were open to the outside air. Hydration status was determined via urine color and urine specific gravity. A urine specific gravity > 1.020 precluded data collection on that day. Each subject then inserted a rectal thermistor 10 cm past the anal sphincter and sat in the shade of the pavilion for 20 minutes.

Baseline. After the 20-minute equilibration period, we collected baseline measures of body weight and rectal body temperature (Trect).

Distance Runs. Immediately after the collection of measures, the subjects proceeded to the starting line to begin their distance runs. We selected the course of each hilly trail run, which consisted of an 8.05-km (5-mile) loop that all subjects completed and a 1.61-km (1-mile) road (asphalt) loop that some subjects continued on; this course was completed twice. Each loop ended at the pavilion. We chose each subject’s running distance based on running ability (8.05, 9.66, 11.27 km [5, 6, or 7 miles, respectively] per loop), with a total distance per trial of 16.09, 19.31, or 22.53 km (10, 12, or 14 miles), based on an in-depth discussion with each subject to determine normal training pace, normal training volume, and normal training distance. We decided which length could be complet-

Figure 1. Timeline of experimental protocol. I indicates immersion; PI, postimmersion.
ed in approximately 90 minutes (of total running) and be conducted at a “challenging yet comfortable” pace. The total distance for each trial was kept constant for each subject. The subjects were briefly stopped (for 3 minutes, not included in the total time of the distance run) midway through the run distance to assess T_{re} (for subject safety). The average distance run was 19 \pm 0.5 km (11.81 \pm 0.03 miles).

Preimmersion. After the distance run, the subjects came into the pavilion, where we measured body weight and T_{re}. All subjects began immersion 2 to 4 minutes after completing the distance run.

Immersion. Using a random, crossover design, the subjects were assigned to mock immersion (no water, air temperature = 28.88 \pm 0.76°C), ice-water immersion (5.15 \pm 0.20°C), or cold-water immersion (14.03 \pm 0.28°C). Each subject was immersed from the shoulders to the hip joints for 12 minutes in a tub (dimensions: 145 cm long, 69 cm wide, 26 cm deep) that was set up in the shaded pavilion. During each immersion, we measured T_{re} and water temperature each minute.

Postimmersion. After immersion, we measured T_{re} at minutes 3, 6, 10, and 15. During this time, the subjects dried off and were allowed to walk around and stretch. They were required to stay within the shaded pavilion during this time.

Measurements

We measured urine specific gravity using a refractometer (Atago URICON-NE, Farmingdale, NY), urine color using a validated urine color chart, T_{re} using a rectal temperature probe (YSI Inc, Yellow Springs, OH), and water temperature using a thermometer (Model 4600, YSI Incorporated). Wet-bulb and dry-bulb temperatures were determined using a sling psychrometer (Bacharach Inc, Pittsfield, PA), black globe temperature via a homemade device, and WBGT via a standard calculation. We measured body weight using a Tanita scale, model BWB-800A (Tanita Corp, Tokyo, Japan) and analyzed body fat using a handheld bioelectric impedance analyzer (model HBF-301, Omron, Vernon Hills, IL). Percentage of dehydration was calculated using the difference between the prerun body weight and the preimmersion body weight (no food or fluid was consumed during this time). Cooling rates were determined by the decrease in rectal temperature (in °C) over a set period of time (per minute).

Statistical Analyses

We analyzed variables using a 2-way (condition × time) analysis of variance with repeated measures (Statistica, StatSoft, Tulsa, OK). The 3 conditions were mock immersion, ice-water immersion, and cold-water immersion. Significant F ratios were analyzed using a Newman-Keuls post hoc test. The level of significance was chosen as P < .05. All data are presented as mean ± standard error of the mean.

RESULTS

Prerun T_{re}, preimmersion T_{re}, WBGT, and percentage of dehydration preimmersion were not significantly different (P > .05) among treatments (Table 1).

Ice-water immersion and cold-water immersion had significantly greater (P < .05) cooling rates than mock immersion at 10 minutes and every point thereafter (Table 2). Even though these values were not statistically significant, there was a trend for ice-water immersion and cold-water immersion to have greater cooling rates than mock immersion for the first 4 and 8 minutes (Figure 2).

Rectal temperatures were greater (P < .05) for mock immersion than for ice-water immersion and cold-water immersion at 12 minutes of immersion and 3, 6, and 15 minutes postimmersion (Figure 3). Rectal temperatures were less (P < .05) for ice-water immersion than for cold-water immersion and cold-water immersion at 3 and 5 minutes postimmersion (Figure 3).

Table 1. Preimmersion Values

<table>
<thead>
<tr>
<th></th>
<th>Time of Distance Run (s)</th>
<th>Baseline T_{re} (°C)</th>
<th>Preimmersion T_{re} (°C)</th>
<th>Percentage of dehydration</th>
<th>WBGT (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mock immersion</td>
<td>5142 ± 108</td>
<td>36.89 ± 0.08</td>
<td>39.31 ± 0.15</td>
<td>3.60 ± 0.22</td>
<td>27 ± 1</td>
</tr>
<tr>
<td>Ice-water immersion</td>
<td>5242 ± 110</td>
<td>37.02 ± 0.09</td>
<td>39.51 ± 0.18</td>
<td>3.89 ± 0.22</td>
<td>27 ± 1</td>
</tr>
<tr>
<td>Cold-water immersion</td>
<td>5208 ± 109</td>
<td>36.89 ± 0.14</td>
<td>39.62 ± 0.15</td>
<td>3.61 ± 0.16</td>
<td>27 ± 1</td>
</tr>
</tbody>
</table>

*WBGT indicates wet-bulb globe temperature. There were no significant differences (P > .05). Values expressed as mean ± SEM.

Table 2. Mean Cooling Rates (°C-min⁻¹) ± SEM During and After Immersion

<table>
<thead>
<tr>
<th>Time</th>
<th>Mock Immersion</th>
<th>Ice-water Immersion</th>
<th>Cold-water Immersion</th>
</tr>
</thead>
<tbody>
<tr>
<td>SI to 8 min</td>
<td>0.13 ± 0.02</td>
<td>0.18 ± 0.03</td>
<td>0.16 ± 0.01</td>
</tr>
<tr>
<td>SI to 10 min†</td>
<td>0.11 ± 0.01</td>
<td>0.16 ± 0.02</td>
<td>0.17 ± 0.02</td>
</tr>
<tr>
<td>SI to 12 min†</td>
<td>0.10 ± 0.01</td>
<td>0.16 ± 0.01</td>
<td>0.16 ± 0.01</td>
</tr>
<tr>
<td>SI to 3 min PI†</td>
<td>0.09 ± 0.00</td>
<td>0.13 ± 0.01</td>
<td>0.13 ± 0.01</td>
</tr>
<tr>
<td>SI to 6 min PI†</td>
<td>0.07 ± 0.01</td>
<td>0.12 ± 0.01</td>
<td>0.11 ± 0.01</td>
</tr>
<tr>
<td>SI to 10 min PI†</td>
<td>0.07 ± 0.00</td>
<td>0.10 ± 0.01</td>
<td>0.09 ± 0.01</td>
</tr>
<tr>
<td>SI to 15 min PI†</td>
<td>0.06 ± 0.00</td>
<td>0.09 ± 0.01</td>
<td>0.08 ± 0.01</td>
</tr>
</tbody>
</table>

*SI indicates start of immersion; PI, postimmersion.
†Ice-water immersion and cold-water immersion showed significantly greater cooling rates than mock immersion (P < .05).

Figure 2. Cooling rates during immersion. SI indicates start of immersion; IWI, ice-water immersion; CWI, cold-water immersion; MI, mock immersion. *IWI and CWI had significantly greater cooling rates than MI (P < .05).
Figure 3. Changes in rectal temperatures during the 12 minutes of immersion and 15 minutes of postimmersion. IWI indicates ice-water immersion; CWI, cold water immersion; MI, mock immersion.

 mock immersion at 6 and 10 minutes postimmersion (Figure 3).

DISCUSSION

At present, views conflict as to the best mode of rapidly cooling hyperthermic athletes. Given that immersion is a widely accepted mode of body cooling, endorsed by organizations such as the American College of Sports Medicine, the International Amateur Athletic Federation, and the United States Military, we conducted this study to determine whether ice-water immersion or cold-water immersion is superior in cooling hyperthermic runners. The cooling rates found in this study are consistent with immersion cooling rates found by other investigators. In soldiers suffering from heat stroke with Trec of 41.7°C or higher, ice-water immersion had a cooling rate of 0.15°C/min⁻¹ with a mean time of 19.2 minutes of immersion.5 In an earlier study, male and female distance runners with a preimmersion Trec of 41.7 ± 0.2°C were cooled at rates of 0.20 ± 0.02°C/min⁻¹ in ice water (1 to 3°C) for 5.6 ± 0.6 minutes.13 We found that cooling rates with torso immersion in cold water were similar to those in a recent study.23 The cooling rates we found for ice-water immersion and cold-water immersion are greater than reported cooling rates for other modes of cooling: passive cooling (0.054°C/min⁻¹), 6 cold packs placed on large arteries of the neck, axillae, and groin (0.049°C/min⁻¹), body covered with 24 to 48 cold packs (0.074°C/min⁻¹), evaporative cooling in which water was splashed onto the body and evaporated by a compressed air spray (0.081°C/min⁻¹), evaporative cooling plus 6 cold packs (0.086°C/min⁻¹), and whole-body immersion at 25°C (0.075°C/min⁻¹).8 Whole-body immersion at 12°C (between our 2 temperatures) had a significantly greater cooling rate (0.262°C/min⁻¹, P < .01) than the other modes of cooling.8

In the only previous study comparing ice-water immersion and cold-water immersion cooling rates, researchers found no difference between ice-water immersion (1 to 3°C) and cold-water immersion (15°C to 16°C) in dogs.17

With similar Trec at the start of all immersions, we found that ice-water immersion (0.16 ± 0.01°C/min⁻¹) and cold-water immersion (0.16 ± 0.01°C/min⁻¹) at 12 minutes induced cooling rates that were both significantly greater (P < .05) than mock immersion (0.10 ± 0.01°C/min⁻¹), although ice-water immersion and cold-water immersion cooling rates were not significantly different from each other (P > .05) (see Table 2). The significant difference between ice-water immersion and cold-water immersion cooling rates as compared with mock immersion was not observed until after 8 minutes of immersion. This implies that hyperthermic athletes being cooled by immersion in water at 5°C or 14°C may need to be immersed for longer than 8 minutes. In addition, in the ice-water and cold-water immersion groups, rectal temperatures continued to decrease significantly faster postimmersion. Thus, water-immersion times similar to our protocol may provide additional cooling when the athlete must be transported for additional medical treatment.

We measured rectal temperatures in this study for the practical ease and validity of measuring core temperature. However, it is likely that core temperature was changing more rapidly in the 2 water-immersion therapies than we could measure with the rectal temperature, given that rectal temperatures usually lag behind true core temperatures by about 10 minutes.24 This would explain why we did not find a statistical difference in cooling rates between the immersion therapies and the mock immersion after 8 minutes.

There are several possible explanations for why ice-water immersion and cold-water immersion did not lead to different cooling rates. The 2 temperatures (5°C and 14°C) may have been too similar to cause a physiologic difference in cooling rates. Another explanation is an alteration in the magnitude of peripheral vasoconstriction between the 2 modes of cooling. The vasoconstriction was not enough to interfere with body cooling; although the peripheral vasoconstriction may have been different between the water-immersion groups, it was not enough to alter the cooling rates.13

Consistent with the data regarding cooling rates, the immersion therapies led to lower Trec than mock immersion at the completion of immersion and throughout the postimmersion period (Figure 3). Also, ice-water immersion induced lower Trec than cold-water immersion at 6 and 10 minutes postimmersion. Ice-water immersion stimulated a greater cooling rate after removal from the immersion bath, but this was negated by 15 minutes postimmersion. It is critical to note that these rectal temperatures do not translate into different cooling rates between ice-water immersion and cold-water immersion, due partly to the slightly higher (although not significantly different) preimmersion rectal temperatures in the cold-water immersion treatment group.

The superior cooling rates for ice-water immersion and cold-water immersion may have significant practical implications for the athletic trainer. Body cooling is known to be advantageous in lowering rectal temperature, as we have shown immersion (at either 5°C or 14°C) to be superior to no immersion. At the onset of immersion (less than 8 minutes), no significant differences among ice-water immersion, cold-water immersion, and mock immersion were found, yet there was a trend toward greater cooling rates with ice-water and cold-water immersion as compared with mock immersion. The known lag in rectal temperatures behind the actual core temperatures could have prevented significant differences from being found. Therefore, we recommend ice-water or cold-water immersion even when time is limited before the arrival of emergency medical service personnel.
Potential side effects of ice-water immersion and cold-water immersion, such as hypothermic overshoot, peripheral vasoconstriction hindering a cooling response, and cardiogenic shock, did not occur during our study. The absence of these side effects is consistent with previous findings using immersion to cool hundreds of hyperthermic individuals. In our study, cooling did continue after removal from the ice-water or cold-water immersion. Although this continued cooling restored rectal temperature more quickly, normal baseline measures were not overshot.

We acknowledge some limitations to this study. Even though we found no significant differences between the WBGT in the crossover design and the averages were similar for all 3 treatments, this was a field study and the same weather conditions were not present for each individual trial. In addition, the hyperthermia of our subjects was of a limited nature compared with that normally found in exertional heatstroke patients. In future endeavors, we intend to compare the effects of ice-water and cold-water immersion on cooling rates of exertional heat stroke patients from a large-scale event, so as to not have to extrapolate our findings. We also aim to compare cooling rates via different modes in a controlled laboratory environment. Additionally, examining what effect movement of the water has during immersion therapy may be important because it may increase cooling rates.

Based on this study, we suggest using either ice-water or cold-water immersion when treating hyperthermic athletes. When an immersion tub is not available, alternative measures of cooling (cold-wet towels, ice packs, evaporative cooling) should be used until medical assistance arrives.

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REFERENCES