

## Reduction in body temperature using hand cooling versus passive rest after exercise in the heat

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### Abstract:

**Objectives:** To examine the effects of hydration and hand cooling on lowering body temperature after exercise in the heat. **Design:** Randomized cross-over design. **Methods:** Nine recreationally active male participants (mean  $\pm$  SD; age,  $24 \pm 4$ ; height,  $177.3 \pm 9.9$  cm; body mass,  $76.7 \pm 11.6$  kg; body fat,  $14.7 \pm 5.8\%$ ) completed a bout of treadmill exercise in a hot environment. After completion of exercise, participants were assigned to the following trials for post-exercise cooling: (1) hydrated with passive rest (HY), (2) hydrated with hand cooling on both hands (HY + 2HC), (3) dehydrated with passive rest (DY), and (4) dehydrated with hand cooling on both hands (DY + 2HC). Within subject differences were assessed using a three-way (Hydration  $\times$  Condition  $\times$  Time) repeated measures ANOVA with Tukey's post hoc analysis if significant interactions were found. **Results:** Irrespective of hydration status, hand cooling on both hands resulted in significantly greater reductions in  $T_{REC}$  than passive cooling at minute 20 ( $0.27^\circ\text{C}$  [0.05, 0.49],  $ES = 2.08$ ,  $p = 0.017$ ) (Fig. 1). The reduction in  $T_{REC}$  at minute 18 trended towards statistical significance ( $0.21^\circ\text{C}$  [0.003, .42],  $ES = 1.59$ ,  $p = 0.053$ ). Hydration status alone and when differentiated among modes of cooling showed no differences on changes of  $T_{REC}$  or heart rate across all conditions during post exercise recovery ( $p > 0.05$ ). **Conclusions:** Hand cooling on both hands reduced  $T_{REC}$  more than passive cooling, however, the cooling rates observed render hand cooling a poor option for cooling. Greater reductions in  $T_{REC}$  after exercise or between bouts of exercise may enhance recovery and subsequent performance.

**Keywords:** Exertional heat illness | Thermal sensation | Exercise recovery | Rectal temperature | Hydration

### Article:

#### 1. Introduction

During intense exercise in the heat, it is common for athletes to reach body temperatures in excess of 39°C.<sup>1</sup> As body temperature increases to hyperthermic levels, athletes are at risk for both performance decrements and exertional heat illnesses (EHI). Furthermore, evidence suggests an inability to fully recover between successive bouts of exercise if body temperature remains elevated.<sup>1,2</sup> Thus, utilizing cooling modalities that are expedient and portable may provide athletes the ability to mitigate the rapid rise of body temperature, during and after exercise, which in turn may prevent performance degradation.

Adequate hydration is fundamental to health and performance during prolonged exercise in the heat. Dehydration increases the risk of EHI by reducing the body's ability to dissipate heat through sweat evaporation, thus leading to a diminished cooling capacity.<sup>3,4</sup> Furthermore, an individual in a hypohydrated state experiences increased cardiovascular strain compared to a euhydrated state, primarily due to the reduced plasma volume leading to a reduced cardiac output.<sup>5,6</sup> Dehydration on a magnitude of >2% body mass loss has been shown to result in performance decrements,<sup>7,8</sup> thus necessitating the need to minimize fluid losses during exercise.

CoreControl™, powered by Rapid Thermal Exchange (RTX) technology, is a portable hand-cooling device, which utilizes negative pressure with circulating cool water to extract heat from the palm of the hand. Its application to the palm is designed to enhance heat removal from this glabrous skin region. Glabrous skin contains arteriovenous anastomoses, a unique, superficial vascular structure connecting the arterioles and veins thus bypassing the capillary beds. Dilation of these arteriovenous anastomoses occurs during exercise heat stress<sup>9,10</sup> and can be further enhanced under subatmospheric pressure,<sup>11</sup> thus increasing skin blood flow to the palms. It is theorized that the combined increase in blood flow and application of cool circulating water promotes heat exchange between the body's core and the surrounding environment, allowing RTX to potentially decrease internal body temperature.

The effectiveness of RTX on decreasing internal body temperature remains inconclusive. Studies have shown this device as having cooling rates greater than passive rest; however, long cooling periods of up to 50 min provided only modest decreases in core body temperature.<sup>12,13</sup> Grahn et al. showed attenuation of rise in esophageal temperature while exercising in a hot environment using RTX,<sup>14</sup> while Amorim et al.<sup>15</sup> found this device to be ineffective in slowing the development of hyperthermia. When comparing cooling of one hand versus two hands, application of the RTX to both hands showed additive benefits to post-exercise esophageal cooling rate.<sup>16</sup>

Given the varying scientific evidence, a further investigation into the efficacy of using the RTX is warranted to understand its full potential in enhancing recovery after exercise in the heat. Specifically, the effects of hydration on RTX efficacy following exercise in the heat have not been explored. Therefore, the purpose of this study was to examine the efficacy of using hand cooling in various hydration states on lowering body temperature after intense exercise in the heat. It was hypothesized that cooling both hands while maintaining a euhydrated state would result in the greatest cooling rate after intense exercise in the heat.

## **2. Methods**

Nine male participants (mean  $\pm$  SD; age,  $24 \pm 4$ ; height,  $177.3 \pm 9.9$  cm; body mass,  $76.7 \pm 11.6$  kg; body fat,  $14.7 \pm 5.8\%$ ) participated in this study. All participants were recreationally active and partook in regular endurance exercise three to four days per week. All participants read and signed an informed consent form approved by the Institutional Review Board at the University of Connecticut prior to participation in the study.

Participants completed a familiarization session before they were randomly assigned to four exercise sessions. The familiarization session required all participants to arrive to the laboratory on three consecutive days to measure urine specific gravity (USG) (Atago Model N-1, Tokyo, Japan) and nude body mass (NBM) (Defender 5000, OHAUS, Parsippany, NY) to calculate baseline values. Participants were instructed to drink 500 mL of water the night prior and the morning of each baseline day, as well as arrive fasted, in order to ensure accurate hydration and NBM measures. These baseline measures were obtained to confirm that our exercise protocol criteria (hydrated and dehydrated) were met during the data analysis. Following the three-day baseline measurement, participants completed a sweat rate assessment in an environmental chamber (Minus-Eleven Inc., Weymouth, MA) where conditions averaged an ambient room temperature of  $39.3 \pm 1.0^\circ\text{C}$ , relative humidity of  $37.6 \pm 6.0\%$ , and wet bulb globe temperature of  $31.2 \pm 1.4^\circ\text{C}$ . During this protocol, participants first provided a urine sample to ensure a euhydrated state ( $\text{USG} \leq 1.020$ ), followed by measurements of height to the nearest 0.1 cm, NBM, and body fat percentage using 3-site skin-folds (Lange Skinfold Caliper, Cambridge, MD) at the chest, abdomen, and thigh measurements using the Jackson-Pollock method.<sup>17</sup> Participants then inserted a rectal thermometer (Measurement Specialties, Hampton, VA) 10 cm past the anal sphincter and donned a heart rate (HR) monitor (Race Trainer, Timex Group, Middlebury, CT) for assessment of rectal temperature ( $T_{\text{REC}}$ ) and HR during the sweat rate testing.

Participants equilibrated to the heat in the environmental chamber for 10 min prior to the start of the sweat rate assessment. The exercise protocol consisted of 10 min walking (5% grade, self-selected pace  $4.8\text{--}7.2$  km  $\text{h}^{-1}$ ) followed by 20 min jogging (1% grade, self-selected pace  $8.0\text{--}12$  km  $\text{h}^{-1}$ ) on a motorized treadmill (NordicTrack 2950 Commercial Treadmill, ICON Health & Fitness, Logan, UT). Next, participants were familiarized on the use of the hand cooling unit (CoreControl™, AVAcore Technologies, Ann Arbor, MI) to be used during the four subsequent exercise sessions. The hand-cooling device exhibited a thermal load of  $17.2^\circ\text{C}$  on the hand in addition to a sub-atmospheric vacuum equivalent to 15 mmHg. The vacuum seal was disrupted every 3 min for the re-establishment of atmospheric pressure to prevent blood pooling in the hand throughout the 20-min cooling bout. Finally, a post exercise NBM was obtained for sweat rate calculation used to determine the participant's fluid consumption during each of the exercise sessions. The sweat rate was calculated using the following equation:

$$\text{Sweat Rate (L/h)} = \left( \frac{\text{Post NBM(kg)} - \text{Pre NBM(kg)}}{\text{Pre NBM (kg)}} \right) \times \text{duration (h)}$$

Following the familiarization session, participants were assigned to four exercise sessions using a randomized crossover design: (1) hydrated with passive rest (HY), (2) hydrated with hand cooling on both hands (HY + 2HC), (3) dehydrated with passive rest (DY), and (4) dehydrated with hand cooling on both hands (DY + 2HC). In hydrated sessions, participants were asked to consume 500 mL of water prior to going to bed and upon waking in the morning. Euhydration

was confirmed by measuring USG ( $\leq 1.020$ ). Fluid consumption during exercise was adjusted accordingly to match 100% of their previously calculated sweat rate. In dehydrated sessions, all participants arrived to the laboratory in a hypohydrated state (refrain from consuming fluids or fluid dense foods for 14 h prior to their arrival to the laboratory) and during exercise, fluid consumption was adjusted to replace only 10% of their previously calculated sweat rate. All sessions were separated by at least one day rest, allowing for proper recovery. Participants arrived  $\pm 1$  h from their first exercise session to account for changes in body temperature due to circadian rhythms.

For each exercise session, participants provided a pre exercise NBM and urine sample upon arrival to the laboratory for hydration assessment. In addition to the rectal thermometer and a HR monitor, participants also donned a thermal long-sleeve shirt and leggings (Under Armour, Baltimore, MD) to accelerate the rise in body temperature during exercise. After the 10-min equilibration period in the environmental chamber, all participants began exercise using the same 10-min walk and 20-min jog circuit that was used in the sweat rate assessment. This cycle continued until the participant's  $T_{REC} \geq 39.44^{\circ}\text{C}$  to ensure a hyperthermic state. Participants were permitted to change the speed of the treadmill within the selected walking and jogging ranges if necessary, as the purpose of the exercise protocol was to induce hyperthermia. During exercise,  $T_{REC}$ , fluid consumption, HR, and environmental conditions were measured every 10 min. At the end of exercise, participants were asked to rate their perception of thermal sensation on a scale of 0 (unbearably cold) to 8 (unbearably hot) in 0.5 increments.<sup>18</sup>

After completion of the treadmill exercise, participants stepped off the treadmill, changed into shorts and a t-shirt, and began the 20-min cooling portion of the session (either passive or hand cooling).  $T_{REC}$  and HR were measured every 3 min. After cooling, participants rated their perception of thermal sensation and then exited the environmental chamber to provide a post-exercise NBM and urine sample for hydration assessment.

All statistical analysis was performed using SPSS v.21 (IBM, Armonk, NY). All data are reported as mean  $\pm$  SD. Within subject differences were assessed using a three-way (Hydration  $\times$  Cooling  $\times$  Time) repeated measures ANOVA to examine differences among the four exercise sessions. Tukey's pairwise comparisons were used if significant interactions were observed. Standard effect sizes (ES; Cohen's  $d$ ), classified as trivial ( $< 0.20$ ), small ( $0.20\text{--}0.49$ ), moderate ( $0.50\text{--}0.79$ ), or large ( $> 0.80$ ), as well as mean difference  $\pm$  95% confidence interval (CI) were used to assess the magnitude of the differences between conditions. Perceptual measures were analyzed using non-parametric analyses (Friedman's). Significance level was set a-priori  $p < 0.05$ .

### 3. Results

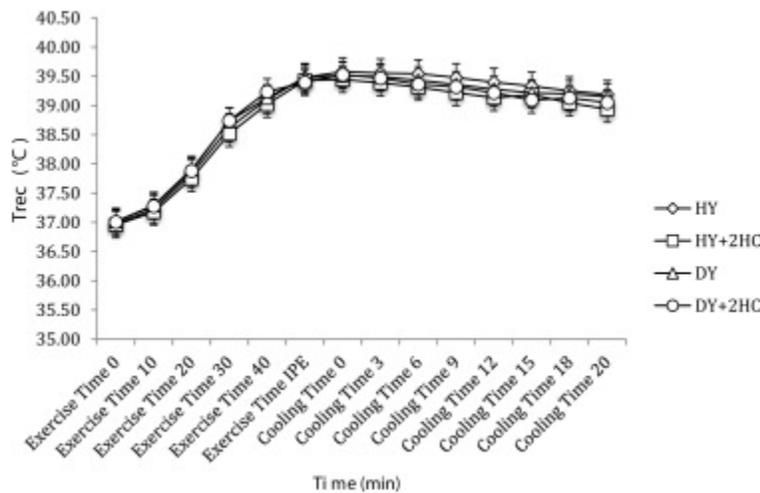
Physiological and perceptual variables during all trials are depicted in Table 1. There were no differences in total exercise time, post exercise  $T_{REC}$ , or post exercise HR ( $p > 0.05$ ) between conditions. Based on the criteria delineating euhydration and hypohydration using USG, participants arrived and finished the trials more hypohydrated in DY and DY + 2HC compared to the other 2 trials ( $p < 0.05$ ). Fig. 1 depicts the exercise and cooling  $T_{REC}$  responses across all four trials.

**Table 1.** Physiological and perceptual variables during exercise sessions across conditions.

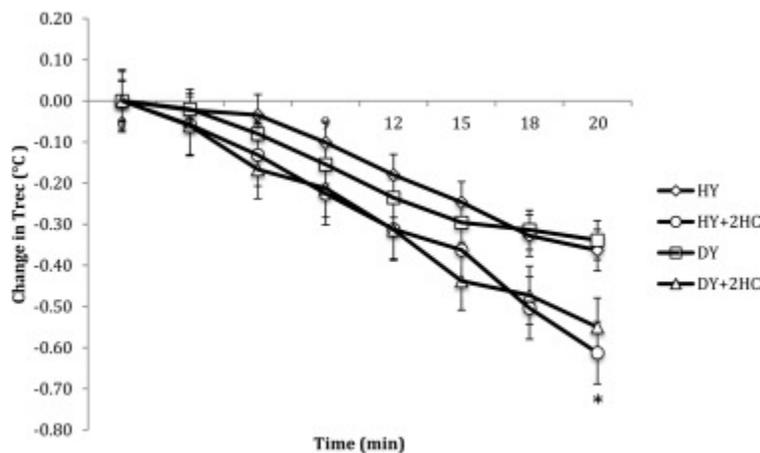
	<b>HY</b>	<b>HY + 2HC</b>	<b>DY</b>	<b>DY + 2HC</b>
Exercise time (min)	46.8 ± 7.1	48.4 ± 5.5	45.3 ± 11.5	43.5 ± 5.5
Post exercise rectal temperature (°C)	39.48 ± 0.28	39.43 ± 0.34	39.47 ± 0.28	39.40 ± 0.36
Post cooling rectal temperature (°C)	39.21 ± 0.35	38.85 ± 0.14	39.15 ± 0.61	39.07 ± 0.55
Post exercise heart rate (b min <sup>-1</sup> )	177 ± 12	172 ± 16	177 ± 9	172 ± 17
Post cooling heart rate (b min <sup>-1</sup> )	129 ± 11	121 ± 13	124 ± 11	123 ± 11
Body mass loss (%)	1.5 ± 0.5	1.1 ± 0.9	3.2 ± 0.8 <sup>a</sup>	3.0 ± 1.1
Pre trial USG	1.011 ± 0.006	1.013 ± 0.006	1.021 ± 0.004 <sup>a</sup>	1.022 ± 0.004 <sup>a</sup>
Post trial USG	1.017 ± 0.006	1.014 ± 0.006	1.027 ± 0.003 <sup>a</sup>	1.025 ± 0.003 <sup>a</sup>
Post exercise thermal sensation <sup>b</sup>	7.5 [7, 7.5]	7.5 [7.0, 8.0]	7.75 [7, 8]	7.75 [7, 8]
Post cooling thermal sensation <sup>b</sup>	5 [4, 5.75]	5 [4, 5]	5.5 [4.75, 6]	5 [5, 6]

<sup>a</sup> Significantly different from HY, HY + 2HC ( $p < 0.05$ ).

<sup>b</sup> Thermal Sensation represented as median [25%, 75% interquartile ranges].



**Figure 1.**  $T_{REC}$  response during exercise and the 20-min cooling period. IPE = Immediate Post Exercise, which refers to the  $T_{REC}$  measure taken at the completion of each exercise bout as referenced in Table 1.



**Figure 2.** Changes in  $T_{REC}$  for HY + 2HC, HY, DY + 2HC, and DY over the 20-min post-exercise cooling period where \* identifies significant difference in the mode of cooling ( $p < 0.05$ ).

During post exercise recovery, irrespective of hydration status, hand cooling on both hands resulted in significantly greater reductions in  $T_{\text{REC}}$  than passive cooling at minute 20 ( $0.27^{\circ}\text{C}$  [0.05, 0.49],  $\text{ES} = 2.08$ ,  $p = 0.017$ ) (Fig. 2). The reduction in  $T_{\text{REC}}$  at minute 18 trended towards statistical significance ( $0.21^{\circ}\text{C}$  [0.003, 0.42],  $\text{ES} = 1.59$ ,  $p = 0.053$ ).  $T_{\text{REC}}$  reductions at all other time points during cooling were not found to be statistically different across all conditions.

Hydration status alone and when differentiated among modes of cooling showed no effect on changes in  $T_{\text{REC}}$  (post cooling–pre cooling) across all conditions during post exercise recovery ( $p > 0.05$ ). Similarly, hydration status or mode of cooling did not influence changes in HR during post exercise recovery ( $p > 0.05$ ).

Regardless of arrival hydration status and fluid replacement during exercise, there were no differences in thermal sensation immediately post exercise in any group (Table 1). Furthermore, utilizing the hand-cooling device did not result in a significant reduction in thermal sensation compared to the trials where participants passively cooled ( $p > 0.05$ ).

#### 4. Discussion

The aim of our study was to investigate the influence of hydration and hand cooling on post exercise recovery after exercise in the heat. We found that changes in  $T_{\text{REC}}$  were greater after a sustained bout of cooling when hand cooling was used on two hands than passive cooling, regardless of hydration status after exercise. Furthermore, we found that HR and thermal perception were not influenced by either hydration or hand cooling after exercise in the heat.

Beginning exercise in a euhydrated state and minimizing fluid losses throughout exercise has been shown to reduce both thermoregulatory and cardiovascular strain during exercise in the heat.<sup>19, 20</sup> Evidence has shown that with every 1% increase in body mass loss, body temperature increases  $\sim 0.22^{\circ}\text{C}$ <sup>8, 21</sup> and HR increases 3 beats  $\text{min}^{-1}$ .<sup>5</sup> The results from our study show that the level of hydration did not affect body temperature and HR immediately after exercise and after a 20-min bout of cooling. This could be due to: (1) the uncompensable environment created by the participants wearing thermal clothing which negated the effects of hydration on mitigating the rise in body temperature,<sup>22, 23</sup> (2) hydration status does not influence the rate of passive cooling after uncompensable heat stress.<sup>24</sup> and (3) participants were permitted to self select their pace which has been previously shown to negate the differences in hydration status on cardiovascular strain.<sup>5</sup>

Previous literature has reported cooling rates for the RTX hand-cooling device to be between  $0.015$  and  $0.07^{\circ}\text{C min}^{-1}$ .<sup>12, 14, 15</sup> When comparing the rates of cooling one versus two hands, Grahn found two hands ( $1.3 \pm 0.2^{\circ}\text{C}/60 \text{ min}$ ) to be greater than one ( $1.0 \pm 0.2^{\circ}\text{C}/60 \text{ min}$ ).<sup>16</sup> This equates to approximately  $0.022^{\circ}\text{C min}^{-1}$  and  $0.017^{\circ}\text{C min}^{-1}$ , respectively. Similarly, we found almost identical cooling rates when cooling of two hands (HY + 2HC,  $0.03 \pm 0.01^{\circ}\text{C min}^{-1}$  and DY + 2HC,  $0.03 \pm 0.02^{\circ}\text{C min}^{-1}$ ) was examined. Likewise, with the passive cooling trials, the associated cooling rates exhibited for HY and DY were  $0.02 \pm 0.02^{\circ}\text{C min}^{-1}$  and  $0.02 \pm 0.02^{\circ}\text{C min}^{-1}$ , respectively. At these rates, it would take over 30-min to lower core body temperature  $1^{\circ}\text{C}$  regardless if hand cooling or passive cooling was utilized to lower body

temperature. These findings support current literature, reaffirming this hand-cooling device's inability to lower body temperature expediently.

The stimulus provided by the RTX to the hand is a thermal load of 17.2°C and the creation of a vacuum equivalent to 15 mmHg. Allowing for this thermal load and vacuum to draw blood into the hand for cooling is predicated on maintaining vasodilation within the AVA structures of the hand. Based on the results of this study, the thermal load placed on the hand may not have been cold enough, or the vacuum seal may have been too great to exhibit a greater cooling effect over that of passive cooling in this study.

Previous studies<sup>15, 16</sup> have found conflicting evidence as to the efficacy of the hand-cooling device in hyperthermic individuals. Similar to the study by Amorim et al.<sup>15</sup> our study used  $T_{REC}$  as the site of body temperature assessment, whereas Grahn et al.<sup>16</sup> utilized esophageal temperature. The difference in location of temperature measurement could influence the purported efficacy of the hand-cooling device as esophageal temperature changes more acutely than rectal temperature. Clinically, rectal temperature changes are more meaningful when monitoring hyperthermic individuals, especially in the treatment of EHI such as exertional heat stroke, where the risk of endotoxemia is high if body temperature remains elevated for a lengthy period of time.

Many cooling devices utilize convection as the mechanism to dissipate heat.<sup>25, 26</sup> In these devices, the cooling source is usually in direct contact with, or indirectly in contact with the skin via thin layer of fabric. These devices are thought to not only mitigate the rise in the internal body temperature, but also reduce thermal sensation to lessen the discomfort from the heat. Our data showed some reduction, although not statistically significant, in the thermal sensation with a 2.5–2.75 unit decrease in both hand cooling trials. An increase in thermal sensation may be a limiting factor for continuation of exercise,<sup>26, 27</sup> therefore, reducing thermal sensation may enhance athletic performance by increasing the exercise capacity. Previous studies<sup>28, 29</sup> have shown the association between the increase in work capacity with the reduction in thermal sensation using cooling devices. This may be especially true when the exercise trial is an open-ended task where the participant is encouraged to perform until volitional exhaustion. However, it should be noted that the increase in thermal sensation is highly associated with the rise in skin temperature, thus, changes in thermal sensation may be more reflective of changes in skin temperature rather than internal body temperature.<sup>30</sup> Unless the cooling modality has been shown to have a clinically meaningful reduction in the internal body temperature, one should not negate the body's signal to cease exercise by the peripheral inputs of thermal discomfort.<sup>27</sup>

The practical applications of the tested hand-cooling device can be delineated from the parameters of this investigation. Based off the observed cooling rates, the hand-cooling device is not an appropriate modality for rapid reduction of body temperature in the treatment of EHI, where the goal of treatment is to reduce body temperature below 40.5°C in under 30 min.<sup>3</sup> Although in situations where other cooling modalities are logistically infeasible, the hand-cooling device may provide additional benefits beyond passive rest. For example, in halftime and intermission periods where full body immersion is too cumbersome, hand cooling can be easily applied to further decrease body temperature. Additionally, in situations where multiple bouts of exercise are separated by rest, hand cooling could potentially mitigate a rise in

body temperature. However, as indicated by our results, the cooling period would need to be sufficiently long, at least 18 min.

## 5. Conclusions

The present investigation is the first to compare hand cooling on two hands and passive cooling on lowering body temperature after exercise in the heat. Also, it is the first to factor the influence of hydration on post exercise cooling, both with and without using a hand-cooling device. Our results suggest that, despite the greater reduction in  $T_{\text{REC}}$  observed in trials with the cooling device on two hands compared to passive rest, the real-world application of this device may lack effectiveness. In addition, differences were only observed when examining the changes in  $T_{\text{REC}}$ , not absolute measures of  $T_{\text{REC}}$ , after a sustained bout of cooling. Consideration should be taken, however, in deciding to use this device above other cooling modalities for post exercise cooling, as demonstrated by the poor cooling rates of the tested hand-cooling device when compared to other cooling modalities (i.e. cold water immersion). Using cooling modalities with greater cooling rates will allow for greater reductions in body temperature after and between bouts of exercise that may have ergogenic effects on exercise performance in subsequent bouts of exercise.

Future research should determine if, despite a low cooling rate, using hand cooling on both hands improves subsequent exercise performance in the heat. It would also be beneficial to examine whether decreasing the temperature of the circulating water within the hand-cooling device allows for a greater reduction in body temperature than what has been previously examined.

## Practical applications

- Cooling considerations should focus on the cooling capacity of the modality used as hydration status does not appear to influence the rate of cooling.
- Using hand cooling on both hands for an extended period of time (20 min) between bouts of exercise may provide additional benefits on reducing body temperature when compared to passive rest.
- Hand cooling should not be considered for the treatment of exertional heat illness due to the poor cooling rate ( $0.03 \pm 0.01^{\circ}\text{C min}^{-1}$ ) compared to other cooling modalities that have a greater cooling capacity (i.e., cold water immersion, rotating ice towels).

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