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Original research

The effects of hydration status and ice-water dousing on physiological and performance indices during a simulated soccer match in the heat

Courteney L. Benjamin [a,b,*], Yasuki Sekiguchi [b], Margaret C. Morrissey [b], Cody R. Butler [b], Erica M. Filep [b], Rebecca L. Stearns [b], Douglas J. Casa [b]

[a] Department of Kinesiology, Samford University, USA
[b] Korey Stringer Institute, Department of Kinesiology, University of Connecticut, USA

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ABSTRACT

Objectives: To assess the effects of hydration status and ice-water dousing on physiological and performance parameters.
Design: Randomized, crossover.
Methods: Twelve athletes (mean[M] ± standard deviation[SD]; age, 20 ± 1 years; height, 174 ± 8 cm; body mass, 72.1 ± 11.0 kg; VO_{2max} 53.9 ± 7.3 mL·kg^{-1}·min^{-1}) completed four trials (euhydrated without dousing, hypohydrated without dousing, euhydrated with dousing, and hypohydrated with dousing), which involved intermittent treadmill running (five 15-minute bouts) in the heat (M ± SD; ambient temperature, 34.7 ± 2.1 °C; relative humidity, 46 ± 3%; wet-bulb globe temperature, 28.0 ± 0.4 °C). Participants also completed four cognitive, power, agility, reaction time, and repeated sprint performance tests throughout each trial. Heart rate (HR) and rectal temperature (T_{rec}) were measured continuously. Repeated measures ANOVAs were performed to assess differences between physiological and performance variables. Alpha was set at ≤0.05, a priori. Data are reported as mean difference ± standard error (MD ± SE).
Results: HR was significantly lower in euhydrated trials compared to hypohydrated trials, irrespective of dousing (8 ± 2 bpm; $p = 0.001$). Dousing did not significantly impact HR ($p = 0.455$) and there was no interaction between hydration and dousing ($p = 0.893$). T_{rec} was significantly lower in euhydrated trials compared to hypohydrated trials (0.39 ± 0.05 °C, $p < 0.001$), with no effect from dousing alone ($p = 0.113$) or the interaction of hydration and dousing ($p = 0.848$). Dousing resulted in improved sprint performance (11 ± 3 belt rotations, $p = 0.007$), while hydration status did not ($p = 0.235$).
Conclusions: Athletes should aim to maintain euhydration during exercise in the heat for improved physiological function and cooling with ice-water dousing elicits additional performance benefits.

Practical implications

- Maintaining euhydration with prescribed fluid intake during a predetermined break resulted in minimal body mass loss (<2%)
- Euhydration resulted in lower heart rate and internal body temperature compared to hypohydration
- Ice-water dousing may provide an additional perceptual and performance benefit during exercise in the heat but should not be substituted for maintaining appropriate hydration

1. Introduction

Field-sport athletes, such as soccer players, often train and compete in the heat. Due to the negative physiological and perceptual outcomes associated with exercise in the heat and the many future international field-sport events scheduled in hot environmental conditions,[1–3] it is vital for athletes to consider heat mitigation strategies.[4,5] Many heat mitigation strategies, such as heat acclimation and ice-vests, have been investigated; however, these methods can require resources, time, planning, equipment, and may be expensive.[6] The ideal heat mitigation strategies to use in team sports is unknown.

Optimal hydration for team sports has been outlined in three basic recommendations that are distinct in their timing: 1) beginning exercise in an euhydrated state, 2) attenuating body-water losses from exercise by adequate fluid consumption, and 3) replacing lost fluid following exercise to return to a euhydrated baseline.[7] While completing all of these items are ideal, it is evident that many team sport athletes do not comply with one or all of these hydration recommendations. For example, 47% of a sample of soccer athletes were in a severely hypohydrated state (urine specific gravity [USG] >1.030) prior to the start of training sessions and matches.[8] National Collegiate Athletic

* Corresponding author.
E-mail address: cbenjami@samford.edu (C.L. Benjamin).

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Association male soccer athletes also demonstrated chronic hypohydration throughout their pre-season, with their USG >1.020 on twelve of fifteen recorded mornings.[9] A recent meta-analysis focused on several heat mitigation strategies demonstrated that fluid intake resulted in enhanced endurance performance outcomes and mitigated the rate of rise in rectal temperature (T_{rec}).[6]

While fluid intake has been established as a method to moderate rises in T_{rec} and heart rate (HR), as well as to optimize endurance performance, mixed-method heat mitigation strategies are highly recommended.[6,10] Cooling modalities are typically utilized at three time points surrounding training or competition: 1) pre-cooling (prior to the start of the event, 2) per-cooling (during the event), and 3) post-cooling (following the cessation of exercise).[11] The effectiveness of the use of cooling vests per-cooling have been established recently, however, this method may not be readily available to many athletes because of the high cost.[12] The use of "Facial wind or water spray" for per-cooling demonstrated a moderate performance benefit in a recent meta-analysis (ES = 0.54),[11] however, limited research exists on this method of cooling.

Even though effectiveness of prescribed drinking and cooling have been individually described, limited research exists on the combined impacts of hydration and cooling on physiological and performance outcomes during exercise in the heat. Additionally, very few investigations have examined these items during intermittent exercise in the heat, which applies to a wide variety of team sports played all over the world. Therefore, the aim of this investigation was to assess the effects of hydration status and ice-water dousing on physiological and performance parameters during intermittent exercise in the heat. We hypothesized that euhydrated athletes would outperform hypohydrated athletes, regardless of dousing, and that dousing would lead to an additive benefit.

2. Methods

Twelve field sport athletes were recruited in this study and provided written informed consent (mean[M] ± standard deviation[SD]; age, 20 ± 1 years; height, 174 ± 8 cm; body mass, 72.1 ± 11.0 kg; VO_{2max} 53.9 ± 7.3 $mL \cdot kg^{-1} \cdot min^{-1}$). This study was approved by the institutional review board at the University of Connecticut.

A randomized balanced cross-over research design involving a total of seven visits was utilized for this investigation. Participants completed three consecutive lab visits in the morning (between 0600 and 1000) to assess aerobic fitness, hydration, and baseline values for performance tests. Aerobic fitness and performance tests were performed once on separate days and hydration measures were recorded each day. Following baseline visits, participants completed four exercise trials that involved intermittent treadmill running and four performance test batteries in the heat (M ± SD; ambient temperature [T_a], 34.6 ± 2.1 °C; relative humidity [RH], 46 ± 3%; wet-bulb globe temperature, 28.0 ± 0.4 °C). A fan was placed in front of the treadmill (M ± SD; wind speed, 1.8 ± 0.1 $m \cdot sec^{-1}$). Specific testing procedures for the baseline and trial visits are described below.

To establish a euhydrated baseline, participants were instructed to provide a morning urine sample upon arrival to the lab to assess urine color on a validated urine color chart[13] as well as USG (Model TS400; Reichert Inc., Depew, NY). Participants were required to be euhydrated (USG < 1.020) for each of these baseline sessions. The purpose of this euhydrated baseline was to compare the participant's body mass at the start of exercise trials to these measures. In the event that a urine sample yielded a USG > 1.020, the three-day baseline was re-initiated. Following urination, the participants' nude body mass was assessed (Defender® 7000XtremeW; OHASUS Corp., Parsippany, NJ, USA). On one of the three baseline days, following the nude body mass assessments, participants completed a VO_{2max} test by a graded exercise on a standard treadmill (T150; COSMED, Traunstein, Germany) and on a separate day, participants completed a familiarization of the performance test battery.

The performance battery included cognitive (Trail Making Test (TMT))[14] power (Just Jump; Probotics Inc., Huntsville, AL, USA), agility (foot speed (FS) test and choice reaction (CS) test (QuickBoard; QuickBoard LLC., Memphis, TN, USA), and sprint ability. To begin the performance battery, participants completed the TMT while seated. For these tests, participants were instructed to connect the dots in sequential number order (TMT-A) and sequential number and alphabet letter (TMT-B) without lifting their pen. The time it took participant's to correctly complete these tasks were recorded. Next, the participants were instructed to tap their feet on the front two dots of the quick board as fast as they could for 10 s (FS) and the number of total taps were recorded. After this, the participants completed the CS test, in which they hopped (both feet) on the dot that was lit up on the screen in front of them for 10 s. The number of jumps and errors (jumped to the wrong dot) were recorded. Finally, the participants moved to the non-motorized treadmill for the repeated sprint protocol. The repeated sprints protocol, derived from previous research,[15] involved sprinting maximally on a non-motorized treadmill (Woodway Curve Treadmill; Woodway Inc., Waukesha, WI, USA) for 6 s with a 24-second break, for five repetitions. Utilizing red tape and a hand-held tally counter, a researcher recorded the total number of belt rotations completed for each 6 s sprint. These tests were performed consecutively during each performance battery throughout the trial.

Following baseline visits, participants completed four exercise trials: euhydrated without dousing (EuND), hypohydrated without dousing (HypoND), euhydrated with dousing (EuD), and hypohydrated with dousing (HypoD). Participants completed five 15-minute intermittent exercise bouts on a motorized treadmill that was pre-programmed into the treadmill software. The exercise protocol was modeled from previous literature that used soccer specific game data to create an individualized sport-specific intermittent treadmill protocol.[16,17] For this study, the protocol was individualized to each participant's VO_{2max} to ensure similar relative physiological responses to the exercise in the heat. The speed throughout the 15-minute protocol changed every 2 to 8 s. The grade throughout this protocol for all participants was 2%. Since the protocol was made relative to individual's VO_{2max}, the range of speeds varied for each participant. The participant with the lowest VO_{2max} completed a protocol with speeds ranging from 0 kph to 16.3 kph, while the participant with the highest VO_{2max} completed a protocol with speeds ranging from 0 kph to 27.0 kph. The participant completed the identical pre-programmed protocol for each trial.

At the onset of the trial, participants completed a 5-minute warm-up on a motorized treadmill and the first of four performance batteries. Immediately following the first performance battery, the first 15-minute intermittent exercise bout began. Following the first 15-minute bout there was a 10-minute break, in which participants doused with ice-water (EuD and HypoD) and rested in a seated position before beginning the second performance battery. Immediately following the second performance battery, the second 15-minute intermittent exercise bout began. Following the second 15-minute bout, there was a 5-minute break, in which participants doused with ice-water (EuD and HypoD) and rested in a seated position. Next, participants completed the third 15-minute bout. Following the third 15-minute bout there was a 10-minute break, in which participants doused with ice-water (EuD and HypoD), rested in a seated position, and consumed fluid (EuD and EuND). After this break, participants completed the third performance battery. Immediately following the third performance battery, the fourth 15-minute bout began. After the fourth 15-minute bout, there was a 5-minute break, in which participants doused with ice-water (EuD and HypoD) and rested in a seated position. Finally, the fifth 15-minute exercise bout took place. Immediately following this bout, participants completed the final performance test battery.

HR and T_{rec} were recorded every 5 min throughout the trial and rating of perceived exertion (RPE), thermal sensation, thirst, and fatigue were assessed at the beginning and end of each 15-minute bout via validated questionnaires. Participants were asked to rank how hard they were working on a scale of 6–20 (RPE: 7 = Very, Very Light; 19 = Very Very Hard), how hot or cold they felt on a 0.5 incremental scale of 0–8.0 (thermal sensation: 0.0 = Unbearably Cold; 8.0 = Unbearably Hot), how thirsty they felt on a 1 incremental scale of 1 to 9 (thirst scale: 1 = Not Thirst at All; 9 = Very, Very Thirsty), and how fatigued they felt on a 1 point incremental scale of 0 to 10 (fatigue scale: 0 = No Fatigue At All; 10 = Completely Fatigued. Sweat rate (SR) was determined by collecting the participant's nude body mass at the beginning and end of each trial and taking fluid intake into account.

Prior to each trial, urine color and USG were determined. For both euhydrated trials, the participant's urine was assessed upon arrival to the laboratory. If USG was >1.020 but <1.025, participants consumed 500 mL of water before beginning the trial. If USG ≥1.025, the trial was rescheduled for a different day. For the hypohydrated trials, participants were instructed to refrain from consuming fluid or any food items with high fluid content for 22 h prior to the trial. In the euhydrated trials, participants were provided with fluid from a standard water fountain, (temperature of approximately 17 °C), to match their body mass loss (BML) in the middle portion of the trial (SCOUT®, OHASUS Corp., Parsippany, NJ, USA). In the hypohydrated trials, participants were permitted 200 mL of fluid in the middle of the trial in an attempt to blunt the psychological impacts of hypohydration.

Dousing involved the use of specialized shower water bottles that were stored in a cooler (M ± SD; water temperature, 0.08 ± 0.22 °C) throughout the trial (REIGN™, CamelBak, California, USA). Cooling fluid volume for each trial were recorded (M ± SD; EuD fluid volume, 5.2 ± 0.6 L; HyD fluid volume, 5.3 ± 0.3 L) (SCOUT®, OHASUS Corp., Parsippany, NJ, USA). Participants were instructed to evenly distribute fluid on the entire body.

Two-way repeated measures (RM) ANOVAs (dousing: 2 levels, hydration: 2 levels) were used to analyze trial mean physiological, perceptual parameters, and the trial sum of belt rotations during the repeat sprint performance tests. Three-way repeated measures ANOVAs (dousing: 2 levels, hydration: 2 levels, time: first two batteries and second two batteries) were used to assess differences in performance outcomes. For the repeat sprint test, the sum of the belt rotations during each 6 s sprint in the first two performance batteries were considered 'performance battery 1 & 2' and the sum of the belt rotations during each 6 s sprint in the third and fourth performance battery were used for 'performance battery 3 & 4'. For all other performance tests, the average scores for battery 1 and 2 were used for the 'performance battery 1 & 2' and scores from battery 3 and 4 were used for the 'performance battery 3 & 4'. Tukey correction was used for post-hoc analysis. Alpha was set at ≤0.05, a priori. Data are reported as mean difference ± standard error and partial eta squared effect size (ηp^2) from the statistical software used for the analysis. All statistical analyses were completed using Jamovi (The jamovi project (2020). Jamovi (Version1.2)).

3. Results

Hydration indices, including pre-exercise USG and urine color, pre-exercise %BML from the 3-day baseline body mass measures, post-exercise %BML from 3-day baseline measures, and post-exercise %BML from the pre-exercise measures can be seen in Table 1. By design, participants did not lose more than approximately 2% of their body mass at the end of exercise by matching fluid intake at half-time to their BML in the first half in the euhydrated trials. In the hypohydrated trials, participants demonstrated approximately 2% BML from pre-exercise and between approximately 3–4% BML from the 3-day euhydrated baseline. Dousing resulted in a lower SR than no dousing (MD ± SE = 0.21 ± 0.05 L·h^{-1}, f(1,11) = 19.03, $p = 0.001$, $\eta p^2 = 0.63$) and hypohydration resulted in a lower SR than euhydration (MD ± SE = 0.24 ± 0.05 L·h^{-1}, f(1,11) = 24.03, $p < 0.001$, $\eta p^2 = 0.69$). There was no interaction between hydration and dousing (f(1,11) = 1.59, $p = 0.233$, $\eta p^2 = 0.13$).

Physiological and perceptual data for each trial are reported in Table 2. Dousing did not result in lower HR (f(1,11) = 0.60, $p = 0.45$, $\eta p^2 = 0.05$) or T_{rec} (f(1,11) = 2.97, $p = 0.113$, $\eta p^2 = 0.21$) (Fig. 1). Regardless of dousing, euhydration resulted in significantly lower HR (MD ± SE = 8 ± 2 bpm, f(1,11) = 18.19, $p = 0.01$, $\eta p^2 = 0.623$) and T_{rec} (MD ± SE = 0.39 ± 0.05 °C, f(1,11) = 59.81, $p < 0.001$, $\eta p^2 = 0.85$). There was no interaction between dousing and hydration on HR (f(1,11) = 0.02, $p = 0.893$, $\eta p^2 = 0.00$) or T_{rec} (f(1,11) = 0.04, $p = 0.848$, $\eta p^2 = 0.00$). RPE was not impacted by dousing (f(1,11) = 0.93, $p = 0.357$, $\eta p^2 = 0.08$) or hydration status (f(1,11) = 4.37, $p = 0.06$, $\eta p^2 = 0.28$) and there was no interaction (f(1,11) = 0.15, $p = 0.704$, $\eta p^2 = 0.01$). Thermal sensation was significantly lower with dousing (MD ± SE = 0.7 ± 0.1 au, f(1,11) = 20.54, $p < 0.001$, $\eta p^2 = 0.651$) and euhydration MD ± SE = 0.5 ± 0.1 au, (f(1,11) = 28.25, $p < 0.001$, $\eta p^2 = 0.72$) and there was no interaction (f(1,11) = 0.11, $p = 0.749$, $\eta p^2 = 0.01$). Thirst sensation was not affected by dousing (f(1,11) = 0.70, $p = 0.422$, $\eta p^2 = 0.060$) but was significantly greater when euhydrated (MD ± SE = 3 ± 0 au, f(1,11) = 84.12, $p < 0.001$, $\eta p^2 = 0.88$) and there was no interaction ($p = 0.866$). Feelings of fatigue were lower with dousing (MD ± SE = 1 ± 0 au, f(1,11) = 5.12, $p = 0.05$, $\eta p^2 = 0.32$) but were not impacted by hydration (f(1,11) = 2.45, $p = 0.146$, $\eta p^2 = 0.32$) and there was no interaction (f(1,11) = 0.31, $p = 0.586$, $\eta p^2 = 0.03$).

Data from the performance test battery can be seen in Supplemental Table 1. TMA performance improved over time (MD ± SE = 0.9 ± 0.2 s, f(1,11) = 22.83, $p < 0.001$, $\eta p^2 = 0.68$), however, there were no differences in TMA with dousing (f(1,11) = 0.22, $p = 0.646$, $\eta p^2 = 0.02$), euhydration (f(1,11) = 0.14, $p = 0.719$, $\eta p^2 = 0.01$), or the interaction of dousing, hydration, and time (f(1,11) = 1.96, $p = 0.900$, $\eta p^2 = 0.15$). TMB performance also improved over time (MD ± SE = 4.5 ± 1.0 s, f(1,11) = 20.89, $p < 0.001$, $\eta p^2 = 0.66$), however, there was no difference with dousing (f(1,11) = 0.20, $p = 0.667$, $\eta p^2 = 0.02$), euhydration (f(1,11) = 0.31, $p = 0.587$, $\eta p^2 = 0.03$), or the interaction of dousing, hydration, and time (f(1,11) = 0.02, $p = 0.900$, $\eta p^2 = 0.00$).

There were no significant main effects between dousing (f(1,11) = 0.04, $p = 0.85$, $\eta p^2 = 0.00$), hydration (f(1,11) = 3.31, $p = 0.10$, $\eta p^2 = 0.23$), and time (f(1,11) = 1.92, $p = 0.19$, $\eta p^2 = 0.15$) for VJ. There was also no interaction between these variables for VJ (f(1,11) = 0.04, $p = 0.85$, $\eta p^2 = 0.00$). There were no significant main effects between dousing (f(1,11) = 3.2, $p = 0.10$, $\eta p^2 = 0.23$), hydration (f(1,11) = 0.167, $p = 0.10$, $\eta p^2 = 0.01$), and time (f(1,11) = 0.74, $p = 0.41$, $\eta p^2 = 0.06$) for FS. There was also no interaction between these variables for FS (f(1,11) = 0.62, $p = 0.45$, $\eta p^2 = 0.05$). There were no significant main effects between dousing (f(1,11) = 0.05, $p = 0.82$,

Table 1
Descriptive data of trial hydration indices.

Trial type	Starting urine specific gravity au	Starting urine color au	Starting %body mass loss from 3-day baseline %	Ending %body mass loss from 3-day baseline %	Ending % body mass loss from start of trial %	Sweat rate L·h^{-1}
Euhydrated without dousing	1.010 ± 0.007	3 ± 2	−0.41 ± 2.00	0.82 ± 2.06	1.21 ± 0.78	1.62 ± 0.29
Hypohydrated without dousing	1.023 ± 0.005	4 ± 1	2.13 ± 1.75	4.39 ± 2.02	2.30 ± 0.56	1.48 ± 0.26
Euhydrated with dousing	1.009 ± 0.007	3 ± 2	−0.60 ± 1.99	0.83 ± 2.35	1.44 ± 0.68	1.49 ± 0.36
Hypohydrated with dousing	1.025 ± 0.003	6 ± 1	1.68 ± 2.26	3.42 ± 2.56	1.78 ± 0.49	1.44 ± 0.33

Table 2
Physiological outcomes by trial. Data are presented at mean ± standard deviation.

Trial type	Heart rate[a] bpm	Rectal temperature[a] °C	Rating of perceived exertion scale au	Thermal sensation scale[a,b] au	Thirst scale[a] au	Fatigue scale[b] au
Euhydrated without dousing	142 ± 14	38.36 ± 0.47	12 ± 2	5.4 ± 0.6	4 ± 1	4 ± 2
Hypohydrated without dousing	151 ± 13	38.74 ± 0.36	13 ± 2	5.9 ± 0.7	7 ± 1	5 ± 2
Euhydrated with dousing	141 ± 8	38.25 ± 0.33	11 ± 3	4.8 ± 0.4	4 ± 1	4 ± 2
Hypohydrated with dousing	148 ± 10	38.65 ± 0.37	12 ± 3	5.2 ± 0.6	7 ± 1	5 ± 2

[a] Indicates statistically significant main effect for hydration status, $p \le 0.05$.
[b] Indicates statistically significant main effect for dousing, $p \le 0.05$.

$\eta p^2 = 0.00$), hydration (f(1,11) = 0.38, $p = 0.55$, $\eta p^2 = 0.03$), and time (f(1,11) = 0.48, $p = 0.50$, $\eta p^2 = 0.04$) for CR. There was also no interaction between these variables for CR (f(1,11) = 0.11, $p = 0.74$, $\eta p^2 = 0.01$).

Results from the RM 2-way ANOVA indicated that dousing resulted in more total number of treadmill belt rotations than non-dousing (M ± SD, euhydrated without dousing = 176 ± 18 total belt rotations; euhydrated with dousing = 183 ± 31 total belt rotations; hypohydrated without dousing = 162 ± 25 total belt rotations; hypohydrated with dousing = 177 ± 18 total belt rotations). Specifically, dousing (180 ± 25) resulted in more total treadmill belt rotations than non-dousing (169 ± 22) (MD ± SE = 11 ± 3 belt rotations, f(1,11) = 11.17, $p = 0.007$, $\eta p^2 = 0.504$), irrespective of hydration status. There was no difference in the number of total trial belt rotations between euhydrated (179 ± 24) total belt rotations and hypohydrated (169 ± 22) total belt rotations (MD ± SE = 10 ± 8 belt rotations, f(1,11) = 1.58, $p = 0.235$, $\eta p^2 = 0.125$), irrespective of dousing status. There was no statistically significant main effect for the interaction between cooling and hydration status (f(1,11) = 0.271, $p = 0.613$, $\eta p^2 = 0.024$). Post-hoc analysis demonstrated no significant differences in sprint performance between any trials (euhydrated without dousing vs hypohydrated without dousing, $p = 0.536$; euhydrated without dousing vs euhydrated with

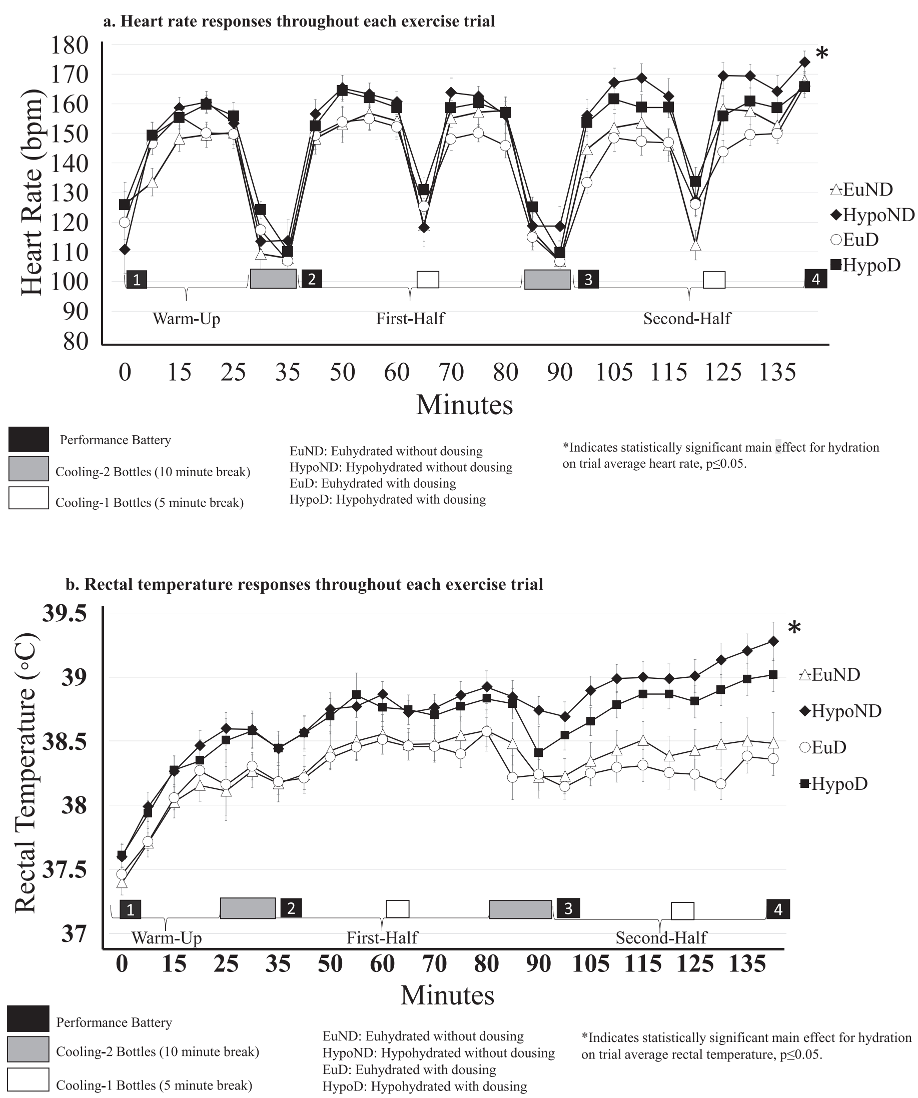

Fig. 1. a and b. Trial heart rate and rectal temperature responses.

dousing, $p = 0.843$; euhydrated without dousing vs hypohydrated with dousing, $p = 0.998$; hypohydrated without dousing vs euhydrated with dousing, $p = 0.137$; hypohydrated without dousing vs hypohydrated with dousing, $p = 0.221$; euhydrated with dousing vs hypohydrated with dousing, $p = 0.954$).

Results from the RM 3-way ANOVA indicated that dousing resulted in more treadmill belt rotations during the sprint test (MD ± SE = 5 ± 2 belt rotations, $f(1,11) = 8.66$, $p = 0.013$, $\eta p^2 = 0.44$), irrespective of hydration status or time. Participants completed fewer belt rotations in testing battery 3 & 4 than testing battery 1 & 2 (MD ± SE = 4 ± 1 belt rotations, $f(1,11) = 8.75$, $p = 0.013$, $\eta p^2 = 0.44$). Sprint performance was not impacted by hydration independently ($f(1,11) = 0.59$, $p = 0.457$, $\eta p^2 = 0.05$), however, there was a significant interaction between time and hydration ($f(1,11) = 11.22$, $p = 0.006$, $\eta p^2 = 0.51$). Specifically, post-hoc analysis revealed that participant's sprint performance significantly declined in performance battery 3 & 4 compared to performance battery 1 & 2 in hypohydrated trials (MD ± SE = 8 ± 2 belt rotations, $p = 0.001$).

4. Discussion

The findings from this study ultimately point to the importance of maintaining minimal fluid losses and the additive benefit of ice-water dousing, particularly for improved perceptual responses and sprint performance. Euhydration resulted in lower HR and T_{rec} while dousing resulted in a lower sweat rate and improved thermal sensation and fatigue. The importance of minimizing fluid losses, regardless of dousing, should not be understated, as euhydration resulted in lower HR and T_{rec}, respectively. While no physiological enhancements were observed with dousing, the improvement in thermal sensation and fatigue is of importance and may explain the improvements in sprint performance with the use of this heat mitigation strategy.

Given the well-established research regarding the importance of athletes competing in a euhydrated state, the physiological results from this study are not surprising, as the increased thermal strain due to uncompensable heat stress can be exaggerated by inappropriate maintenance of euhydration.[7] A recent review states that individuals with high sweat rates and those hoping to optimize exercise performance should consider limiting BML to <2% during exercise, especially in the heat, which was achieved during these euhydrated exercise trials.[18] The impacts of hydration status on T_{rec} and HR were evident throughout the entire trial. Sweat rates have been reported to be lowered in hypohydrated states due to a delayed onset of sweating, and this may explain the lowered sweat rate in hypohydrated trials in this study.[19]

Hydration status did not impact cognitive, power, or agility performance in the current study. The specific cognitive test (TMT) used in this study is a measure of executive function,[20] and the findings from this study can provide evidence to add to the current conflicting results on this topic.[21] In terms of power, the findings from the present study are in support of previous literature that have not seen differences in vertical jump performance between euhydrated and hypohydrated individuals.[22]While previous literature has demonstrated impaired aerobic performance from a pre-exercise hypohydrated state,[23] the findings from this study add to the literature by demonstrating that repeat sprint performance was also negatively impacted later in an exercise bout in hypohydrated trials, evident by the differences in the number of treadmill belt rotations between trials. This outcome contributes to previously studied literature that has mixed results related to repeated sprint performance during exercise in the heat.[24]

While the impacts of hydration status on physiological, perceptual, and performance outcomes were expected, the additive impacts of ice-water dousing used prior to and during exercise are not as well understood.[25] Recent research investigating simulated tennis matches examined the differences between the use of ice towels, an electric fan, and an electric fan with dousing in hot, dry conditions (45 °C, <10% RH). In this study, the use of ice towels resulted in ~0.5–0.6 °C lower internal body temperature compared to a control trial.[26] The use of a fan with dousing also elicited positive outcomes; however, unlike the present study, dousing involved the use of a damp sponge soaked in 15 °C over the head, neck, arms and thighs.[26] The rational for increasing skin wettedness to improve physiological outcomes, such as through ice-water dousing, is to promote evaporative heat loss which reduces thermal strain. The low water temperature used for dousing could have perhaps resulted in local vasoconstriction of the skin arterioles, which would reduce heat transfer via the skin.[27]

Much like hydration status, ice-water dousing did not elicit performance enhancements in cognitive, power, or agility performance in the present cohort. Participants completed more belt rotations during the sprint test with dousing, regardless of hydration status or time. Of note, while there was no statistically significant interaction between hydration status and dousing, the significant main effect for dousing may be attributed to the difference observed between euhydrated with dousing (mean = 183 belt rotations) and hypohydrated without dousing (mean = 162 belt rotations). However, post-hoc testing did not demonstrate significant differences between these trials, most likely due to the large variability observed between participants. While repeat sprint performance has not been heavily investigated with various cooling modalities, a study investigating pre-neck cooling observed improved sprint performance compared to a control trial.[15] This finding is of value to optimize performance in extreme environmental conditions and may be a result of the improved thermal sensation and fatigue measures observed with the use of this modality. Although hydration status did not independently impact sprint performance, hypohydration resulted in decreased sprint performance later in the exercise bout. This finding is most likely due to the higher T_{rec} in hypohydrated trials, as an elevated internal body temperature can result in poor performance outcomes.[28]

While the current study provided useful information about the effectiveness of hydration and ice-water dousing, it is not without limitations. One limitation of the current study is that while the authors attempted to design an individualized exercise protocol by controlling for VO_{2max}, previous research has pointed to the value of utilizing metabolic heat production to establish exercise intensity when internal body temperature is a main outcome.[29] Future studies may look to determine if the use of a protocol made to account for metabolic heat production would produce similar responses. Another limitation to the present study is that hypohydration was induced through a 22-hour fluid restricted protocol plus fluid restriction during exercise in the heat. While similar protocols have been utilized to artificially create similar hydration states typically observed in athletes, this protocol can be quite taxing mentally, which could have impacted the performance results. Participants in the present study were provided with 200 mL of fluid at in the middle of the trial in an attempt to reduce the negative psychological responses to this protocol. Future studies could improve these methods by inducing hypohydration through exercise alone.

5. Conclusion

Hydration status impacts physiological, perceptual, and sprint performance outcomes during intermittent exercise in the heat. Ice-water dousing did not result in improved HR or T_{rec}, however, this heat mitigation strategy led to lower sweat rate and improved thermal sensation, fatigue, and repeat sprint performance. In summary, coaches, sport scientists, and sports medical professionals should ensure euhydration through encouraging fluid intake at the start of activity and by prescribing fluid during long breaks based on BML. Additionally, ice-water dousing seems to provide additional benefits during intense intermittent exercise in the heat and is a practical, cost-effective cooling modality.

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Confirmation of ethical compliance

The authors of this paper confirm that this research was approved by the Institutional Review Board at the University of Connecticut and participants provided written informed consent to participate in this study.

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