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original research

Self-Paced Exercise Performance in the Heat After Pre-Exercise Cold-Fluid Ingestion

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Context: Precooling is the pre-exercise reduction of body temperature and is an effective method of improving physiologic function and exercise performance in environmental heat. A practical and effective method of precooling suitable for application at athletic venues has not been demonstrated.

Objective: To confirm the effectiveness of pre-exercise ingestion of cold fluid without fluid ingestion during exercise on pre-exercise core temperature and to determine whether pre-exercise ingestion of cold fluid alone without continued provision of cold fluid during exercise can improve exercise performance in the heat.

Design: Randomized controlled clinical trial.

Setting: Environmental chamber at an exercise physiology laboratory that was maintained at 32°C, 60% relative humidity, and 3.2 m/s facing air velocity.

Patients or Other Participants: Seven male recreational cyclists (age = 21 ± 1.5 years, height = 1.81 ± 0.07 m, mass = 78.4 ± 9.2 kg) participated.

Intervention(s): Participants ingested 900 mL of cold (2°C) or control (37°C) flavored water in 3 300-mL aliquots over 35 minutes of pre-exercise rest.

Main Outcome Measure(s): Rectal temperature and thermal comfort before exercise and distance cycled, power output, pacing, rectal temperature, mean skin temperature, heart rate, blood lactate, thermal comfort, perceived exertion, and sweat loss during exercise.

Results: During rest, a greater decrease in rectal temperature was observed with ingestion of the cold fluid (0.41 ± 0.16°C) than the control fluid (0.17 ± 0.17°C) over 35 to 5 minutes before exercise ($t_6 = -3.47$, $P = .01$). During exercise, rectal temperature was lower after ingestion of the cold fluid at 5 to 25 minutes (t_6 range, 2.53–3.38, $P \leq .05$). Distance cycled was greater after ingestion of the cold fluid (19.26 ± 2.91 km) than after ingestion of the control fluid (18.72 ± 2.59 km; $t_6 = -2.80$, $P = .03$). Mean power output also was greater after ingestion of the cold fluid (275 ± 27 W) than the control fluid (261 ± 22 W; $t_6 = -2.13$, $P = .05$). No differences were observed for pacing, mean skin temperature, heart rate, blood lactate, thermal comfort, perceived exertion, and sweat loss ($P > .05$).

Conclusions: We demonstrated that pre-exercise ingestion of cold fluid is a simple, effective precooling method suitable for field-based application.

Key Words: precooling, hyperthermia, time trial

Key Points

- Ingestion of 900 mL of cold fluid over 35 minutes of pre-exercise rest produced a mean 0.4°C reduction in pre-exercise rectal temperature and resulted in lower rectal temperature during exercise.
- Self-paced endurance performance in the heat was improved after pre-exercise ingestion of cold fluid.
- Ingesting cold fluid before exercise was a simple, effective precooling method that might be applied at athletic venues before athletes train or compete in the heat.

Precooling is the lowering of body temperature before exercise and consistently has been demonstrated as an effective method of improving physiologic function and exercise performance in environmental heat.[1,2] Precooling before fixed-intensity submaximal exercise lowers thermal, cardiovascular, and perceptual strain and increases time to exhaustion.[1,2] Precooling before self-paced submaximal exercise lowers thermal responses and produces an ergogenic effect. The higher self-selected work rate often is achieved with equivalent cardiovascular and perceptual responses.[1,2]

Precooling methods, such as immersion in cool water (<24°C), exposure to cold air (<5°C), wearing of ice vests, and direct application of cold modalities to muscle, typically result in reduced core or skin temperature and produce an associated ergogenic response.[1,2] For example, researchers have reported that approximately 60 minutes of cool-water (approximately 23°C) immersion reduced exercising rectal (T_{rec}) and skin temperature (T_{sk}) and improved performance in the heat by increasing the distance covered during 30 minutes of self-paced running by 4.2% (0.3 km) and cycling by 6.0% (0.9 km).[3,4] Despite the ergogenic potential of precooling, the major limitation to its widespread adoption at athletic venues is the impracticality of currently established methods.[1,2] Therefore, a precooling method demonstrating utility for field-based use would be desirable to athletes and athletic support personnel.

Lee et al[5] described a practical precooling method suitable for field-based application. They reported that 900 mL of cold (4°C) fluid ingested over 30 minutes before exercise in the heat reduced pre-exercise rectal temperature by 0.5 ± 0.1°C. The effect was comparable in magnitude to conventional precooling methods.[1,2] The cold fluid was well tolerated, as indicated by modest reductions in thermal sensation (from +1 to –2, indicating *some areas of body feel cold*) and no evidence of diuresis. When cold-fluid ingestion was continued during exercise at a rate of 100 mL every 10 minutes, thermal, cardiovascular, and perceptual responses were lower, and cycling time to exhaustion at approximately 66% maximum oxygen consumption ($\dot{V}O_2max$) was improved by 23% (approximately 12 minutes) beyond the control-fluid (37°C) condition.[5] Based on the 0.5°C reduction in pre-exercise rectal temperature, the authors hypothesized that pre-exercise ingestion of cold fluid without continued provision of cold fluid during exercise could improve performance in the heat. However, this hypothesis has not been tested. Lee et al[5] proposed cold-fluid ingestion as a highly practical method, allowing precooling to be achieved at athletic venues with an easily adopted strategy that is consistent with the precompetition fluid intake preparation of athletes.

Therefore, the purpose of our study was to confirm the effectiveness of pre-exercise ingestion of cold fluid on pre-exercise core temperature and to test the hypothesis that pre-exercise ingestion of cold fluid alone without continued provision of cold fluid during exercise can improve exercise performance in the heat. Because the intervention potentially represents a precooling strategy applicable for field-based use, we chose a self-paced performance trial to test the efficacy of the method and increase the ecological validity of the research findings.

METHODS

Participants

Seven male university sports science students (age = 21 ± 1.5 years, height = 1.81 ± 0.07 m, and mass = 78.4 ± 9.2 kg) who were recreational cyclists volunteered to participate in our study. Participants were not heat acclimatized. An initial familiarization session was performed, and then 2 experimental trials were performed at the same time of day (0900 h) 5 to 7 days apart and presented in randomized order. Participants were instructed to consume a high-carbohydrate diet and abstain from consuming alcohol and caffeine and from exercising vigorously for 24 hours before testing. Participants arrived at the laboratory after an overnight fast and the ingestion of 500 mL of water upon waking. They provided written informed consent, and the study was approved by the University of Exeter Ethics Committee.

Precooling Intervention

During 35 minutes of seated rest in an air-conditioned environment (21°C dry bulb temperature, 60% relative humidity, 0 m/s air velocity), participants ingested 900 mL of flavored water with a temperature of 37°C (control fluid) or 2°C (cold fluid). Fluid was provided in 300-mL aliquots at 35, 25, and 10 minutes before exercise and was ingested within 45 s on each occasion. Control-fluid temperature was maintained at 37°C by immersion of a glass beaker containing the fluid in a thermostatically controlled water bath (model GD100; Grant Instruments Ltd, Cambridgeshire, UK). Cold fluid was prepared by mixing refrigerated fluid (approximately 4°C) with ice cubes in a vacuum flask to bring the temperature to 2°C. Drink temperature was measured with a disposable temperature probe (YSI 400 series; YSI, Inc, Yellow Springs, OH) connected to a precision thermometer (YSI Precision 4000A; YSI, Inc). Fluid was poured from the heated glass beaker or vacuum flask into an insulated cup and immediately given to the participants to drink. The cold fluid in the insulated cup contained no ice. Each aliquot comprised 60 mL of sugar-free, orange-flavored cordial and 240 mL of tap water. The energy content of the drink was 8 kcal (0.6 g of carbohydrate, 0.2 g of protein) per 100 mL, providing a total of 72 kcal (5.4 g of carbohydrate, 1.8 g of protein) for the 900 mL. Participants were transferred to an adjacent environmental chamber 5 minutes before exercise.

Exercise Protocol

Environmental conditions were maintained at 32°C dry bulb temperature and 60% relative humidity with a fan positioned directly in front of the participants and providing a 3.2-m/s facing air velocity. The dry bulb and relative humidity matched the prevailing environmental conditions (ie, 33 ± 2°C and 61 ± 13% relative humidity) during the men's cycling road race at the Games of the XXIX Olympiad in Beijing, China, in 2008. The exercise test was conducted on an electronic bicycle ergometry system (CompuTrainer; RacerMate, Seattle, WA), which enabled the volunteers to use their own racing bicycles for performance trials. The system was calibrated according to the manufacturer's instructions before each trial, and the bicycle configuration and tire pressure were kept constant between trials. The exercise protocol consisted of a 30-minute self-paced cycling time trial with participants cycling for maximum distance. Visual feedback indicating exercise time, distance, and power was continuously available. Investigators provided standardized encouragement and feedback at 5-minute intervals, communicating the duration of the test covered and the duration remaining. No fluid was available during the 30 minutes of exercise. Participants undertook a familiarization session that exactly mimicked the experimental trials and drank room-temperature (approximately 20°C) fluid during the resting phase.

Measurements

Upon arrival at the laboratory, participants produced a urine sample for the estimate of urine osmolality, measured with a handheld digital refractometer (Osmocheck; Vitech Scientific Ltd, West Sussex, UK), that was used as an index of hydration status.[6] Nude body mass was measured with a platform scale (model 780; Seca, Hamburg, Germany) to the nearest 10 g before and after each trial to estimate sweat loss after fluid intake and urine output were accounted for. The opportunity to urinate was provided throughout the resting phase. Participants inserted a disposable rectal thermistor (400 series; YSI, Inc) 10 cm beyond the anal sphincter; the thermistor was connected to a precision thermometer (Precision 4000A; YSI, Inc) for measurement of T_{rec} at 5-minute intervals throughout rest and exercise. Mean T_{sk} was calculated as a weighted mean of 4 sites (chest, arm, thigh, calf)[7] recorded at 5-minute intervals during exercise with surface thermistors (type EUS-UU; Grant Instruments Ltd) that were connected to a data logger (Squirrel SQ800; Grant Instruments Ltd). Heart rate was measured by telemetry (Polar Vantage; Polar Electro Oy, Kempele, Finland) at 5-minute intervals throughout exercise. Blood lactate was determined from a fingertip capillary sample (2300 STAT Plus glucose and lactate analyzer; YSI, Inc) immediately before exercise and at 10, 20, and 30 minutes of exercise. Rating of thermal comfort was assessed at 5-minute intervals during rest and exercise using the Bedford scale with the anchors of

1, indicating *much too cool,* and 7, indicating *much too warm.*[8] Rating of perceived exertion (RPE) was assessed at 5-minute intervals during exercise using the Borg[9] scale with the anchors of 6, indicating *no exertion at all,* and 20, indicating *maximal exertion*. Performance was assessed as total distance cycled in 30 minutes. Instantaneous power output was measured at 5-minute intervals, and pacing was quantified at 5-minute intervals as follows:

$$\text{Percentage off mean pace} = [(\text{Power output} - \text{Mean power})/(\text{Mean power})] \times 100,$$

where a positive value represents a pace higher than mean pace, a negative value represents a pace lower than mean pace, and mean power represents the mean of the 5-minute to 25-minute instantaneous power values (chosen because the 30-minute value is affected by the end-spurt phenomenon).

In addition, 1 participant ingested a disposable telemetric temperature sensor (VitalSense; Mini Mitter, Bend, Oregon) immediately before the experimental protocol to quantify stomach temperature ($T_{gastric}$) throughout control-fluid and cold-fluid trials.[10] The ingestible sensor deliberately was administered just before the trial so that it would be in the stomach when fluid was ingested and therefore would provide insight into the magnitude and time course of local gastric cooling in response to the cold fluid.

Statistical Analysis

We used a 2-factor (time × fluid temperature) repeated-measures analysis of variance (ANOVA) to determine the effect of fluid temperature on T_{rec} during rest and exercise, with 8 repeated measures (–35, –5, 5, 10, 15, 20, 25, and 30 minutes) and the 2 fluid temperatures (cold, control). Thermal comfort at 5-minute intervals during rest was analyzed with a 2-factor (time [7] × fluid temperature [2]) repeated-measures ANOVA. Additional 2-factor (time [6 or 3] × fluid temperature [2]) repeated-measures ANOVAs were used to determine the effect of fluid temperature on power output, pacing, T_{sk}, heart rate, blood lactate, thermal comfort, and RPE at 5-minute intervals (10-minute intervals for blood lactate) during exercise. When we found a main effect or interaction, we used paired-samples *t* tests applying the Bonferroni correction procedure. Paired-samples *t* tests were used to investigate differences between experimental conditions for urine osmolality and body mass upon arrival at the laboratory, change in T_{rec} during rest (ie, –35 to –5 minutes), change in T_{rec} during exercise (ie, 5 to 30 minutes), body water balance, and distance cycled in 30 minutes.

The α level was set at .05. Data were analyzed using the SPSS (version 15.0; SPSS Inc, Chicago, IL). Data are presented as mean ± standard deviation unless otherwise stated.

RESULTS

Pre-Exercise Hydration Status

Participants were euhydrated similarly before both trials, as evidenced by comparable estimates of urine osmolality and body mass. Urine osmolality was 317 ± 169 mOsmol/kg [range, 160–560 mOsmol/kg] for the cold-fluid trial and 309 ± 168 mOsmol/kg [range, 130–610 mOsmol/kg] for the control-fluid trial ($t_6 = -0.33$, $P = .75$). Body mass was 78.67 ± 9.02 kg for the cold-fluid trial and 78.42 ± 9.18 kg for the control-fluid trial ($t_6 = -1.25$, $P = .26$).

Core Temperature

Rectal Temperature. An interaction of time by temperature on T_{rec} was observed ($F_{7,35} = 3.39$, $P = .007$). No differences in T_{rec} were evident between conditions at 35 minutes before the first aliquot of fluid was ingested ($t_6 = -0.55$, $P = .60$) or at 5 minutes before exercise ($t_6 = 1.38$, $P = .22$). Rectal temperature was lower after cold fluid than control-fluid ingestion at 5 to 25 minutes (t_6 range, 2.53–3.38, $P \leq .05$) and was lower (approaching significance) after cold-fluid ingestion (38.1 ± 0.3°C) than control-fluid ingestion (38.6 ± 0.5°C) at 30 minutes ($t_6 = 2.46$, $P = .057$). The change in T_{rec} during rest from –35 minutes to –5 minutes was greater with the cold-fluid condition (0.41 ± 0.16°C) than the control-fluid condition (0.17 ± 0.17°C) ($t_6 = -3.47$, $P = .01$). No differences were observed for change in T_{rec} during exercise between the cold-fluid condition (1.3 ± 0.3°C) and control-fluid condition (1.5 ± 0.3°C; $t_6 = 1.50$, $P = .19$). Figure 1 illustrates the T_{rec} response to rest and exercise.

Gastric Temperature. Use of the ingestible temperature sensor in 1 participant revealed dramatic localized reductions in $T_{gastric}$ of 23°C to 24°C with each cold-fluid aliquot and incomplete recovery by the start of exercise (Figure 2A). Gastric temperature recovered to 33°C in the 10 minutes after the first aliquot, to 35°C in the 15 minutes after the second aliquot, and to 31°C in the 10 minutes before the start of exercise after the third aliquot. Figure 2B illustrates the simultaneous measurement of T_{rec} and reveals a more subtle and gradual decline with cold fluid that was typical of the sample response observed in Figure 1. The change in T_{rec} for this participant (0.59°C for the cold-fluid condition and 0.05°C for the control-fluid condition) was also typical of the sample response. At the start of exercise, gastric temperature was lower in the cold fluid (31.3°C) than the control-fluid (37.0°C) conditions, reached equivalence between the cold fluid (37.6°C) and the control-fluid (37.6°C) conditions after 15 minutes, and subsequently became higher in

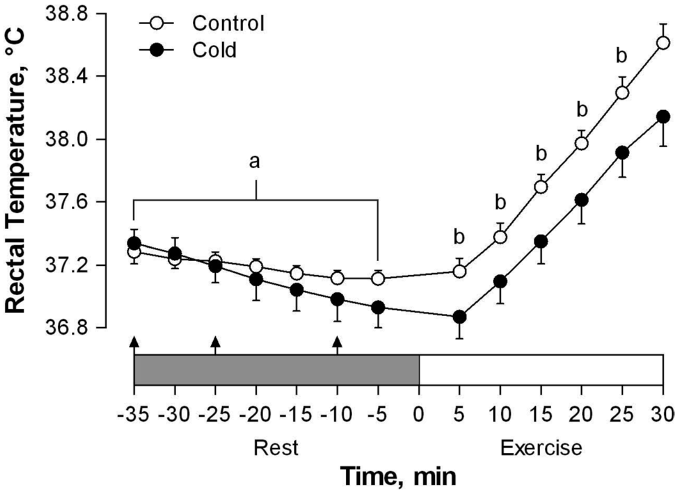

Figure 1. Rectal temperature at rest and during exercise for the 2 experimental trials. Arrows denote the ingestion of 300 mL of fluid with a temperature of 37°C (control) or 2°C (cold). [a]Indicates a greater change in rectal temperature from –35 to –5 minutes for the cold than the control condition (*P* = .01). [b]Indicates a lower rectal temperature for the cold than the control condition (*P* < .05). Values are means ± SEM.

the cold fluid (38.6°C) than the control-fluid (38.0°C) condition at 30 minutes.

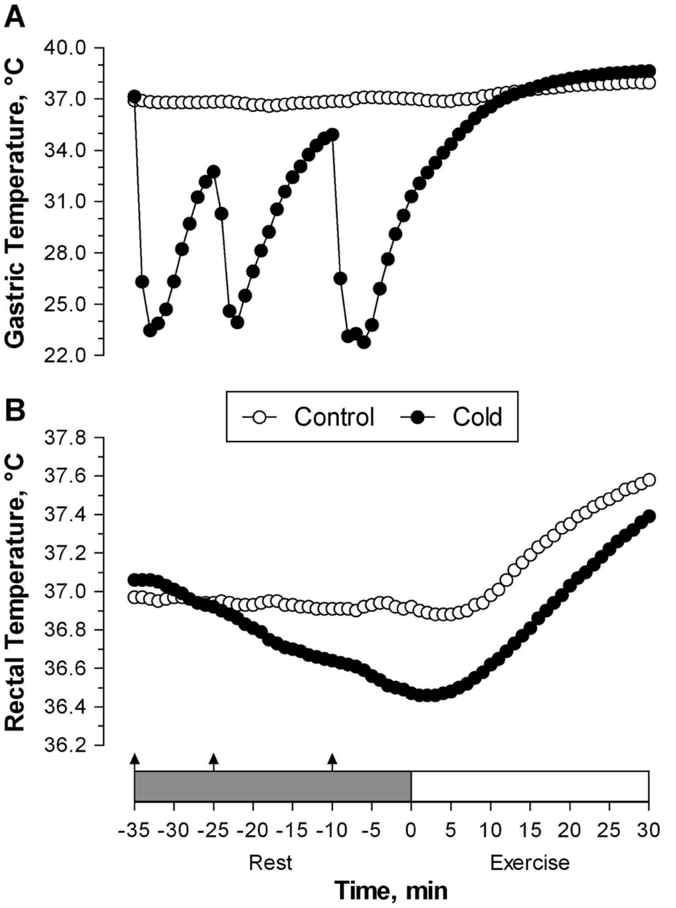

Figure 2. Temperature responses of 1 participant at 1-minute intervals to the 2 experimental trials. A, Gastric. B, Rectal. Arrows denote the ingestion of 300 mL of fluid with a temperature of 37°C (control) or 2°C (cold).

Pre-Exercise Thermal Comfort

We observed an interaction of time by fluid temperature on thermal comfort ($F_{3,18}=10.56$, $P<.001$). No differences in thermal comfort were evident at 35 minutes ($t_6=1.18$, $P=.36$) before the first aliquot of fluid was ingested. Thermal comfort was lower with the cold-fluid (2.3±0.8°C units, with 2 indicating *too cool*) than the control-fluid (3.8±0.4 units, with 4 indicating *comfortable*) condition at –15 and –5 minutes ($t_6=4.15$, $P=.006$ for both). Shivering was observed in 1 participant at the end of the resting period with cold-fluid ingestion.

Skin Temperature, Heart Rate, Blood Lactate, and Perceptual Responses During Exercise

No differences were observed between conditions for T_{sk} ($F_{1,6}=0.15$, $P=.71$), heart rate ($F_{1,6}=0.53$, $P=.49$), blood lactate ($F_{1,6}=0.06$, $P=.81$), RPE ($F_{1,6}=0.02$, $P=.90$), or rating of thermal comfort ($F_{1,6}=0.79$, $P=.41$) (Table).

Body Water Balance

No differences were observed for sweat loss (cold-fluid condition = 0.77±0.40 L, control-fluid condition = 0.98±0.21 L; $t_6=-1.29$, $P=.22$), urine loss (cold-fluid condition = 0.20±0.14 L, control-fluid condition = 0.17±0.23 L; $t_6=-0.34$, $P=.25$), or percentage dehydration (cold-fluid condition = 0.1±0.5%, control-fluid condition = 0.4±0.4%; $t_6=-2.14$, $P=.09$). The proportion of participants urinating after ingesting fluid increased from 43% (n = 3) with the control fluid to 86% (n = 6) with the cold fluid. These participants urinated immediately before exercise and not during exercise.

Table. Physiologic and Perceptual Responses to the 30-Minute Time Trial After Ingestion of Control (37°C) and Cold (2°C) Fluids

	Exercise Time, min					
Variable	5	10	15	20	25	30
Mean skin temperature,[a] °C						
Control	33.5±0.2	34.6±0.3[b]	35.1±0.5[b]	35.3±0.6[b]	35.4±0.7[b]	35.4±0.9[b]
Cold	33.5±0.4	34.6±0.5	35.3±0.4	35.2±0.7	35.2±0.5	35.1±0.3
Heart rate,[a] beats/min						
Control	160±11	168±12[b]	172±12[b]	177±10[b,c,d]	182±7[b,c,d,e]	190±8[b,c,d,e]
Cold	156±11	168±9	173±7	176±7	181±8	189±9
Blood lactate,[a] mmol/L						
Control	Not measured	6.1±2.4	Not measured	6.1±2.5	Not measured	8.8±1.9[c,e]
Cold	Not measured	5.5±1.5	Not measured	5.8±2.4	Not measured	8.7±3.5
Rating of perceived exertion[a,f]						
Control	14.4±1.3	15.1±1.2[b]	15.7±1.5	16.7±1.4[b]	17.6±1.6[b,c,d,e]	18.7±1.5[b,c,d,e]
Cold	14.1±1.6	15.0±1.4	15.7±1.3	16.6±1.1	17.9±1.1	19.1±1.1
Rating of thermal comfort[a,g]						
Control	5.4±0.8	5.7±0.8[b]	6.1±0.9[b]	6.3±0.8[b]	6.6±0.8[b]	6.7±0.5[b,c]
Cold	5.0±0.8	5.6±0.5	6.0±0.6	6.3±0.8	6.7±0.5	6.9±0.4

[a] Indicates a main effect for time ($P<.01$).

[b] Indicates higher than 5-minute value for both conditions ($P<.05$).

[c] Indicates higher than 10-minute value for both conditions ($P<.05$).

[d] Indicates higher than 15-minute value for both conditions ($P<.05$).

[e] Indicates higher than 20-minute value for both conditions ($P<.05$).

[f] The Borg scale[9] is anchored by 6, indicating *no exertion at all,* and 20, indicating *maximal exertion*.

[g] The Bedford scale[8] is anchored by 1, indicating *much too cool,* and 7, indicating *much too warm*.

Exercise Performance

Distance. The distance cycled in 30 minutes was greater after cold-fluid (19.26 ± 2.91 km) than control-fluid (18.72 ± 2.59 km) ingestion ($t_6 = -2.80$, $P = .03$) (Figure 3). The mean difference was 0.536 ± 0.505 km, the 95% confidence interval for the mean difference was –0.078 to 1.008 km, and the mean relative improvement was 2.8 ± 2.4%.

Power. We observed main effects for time ($F_{5,30} = 18.74$, $P < .001$) and drink temperature ($F_{1,6} = 5.71$, $P = .05$). The mean power was greater after cold-fluid (275 ± 27 W) than control-fluid (261 ± 22 W) ingestion ($t_6 = -2.13$, $P = .03$) (Figure 4A). The mean difference was 14 ± 15 W, and the 95% confidence interval for the mean difference was 0 to 27 W. Power output at 30 minutes was higher than power output at all other time points (t_{13} range = –4.79 to –5.80, $P < .001$).

Pacing. We did not observe a main effect for drink temperature ($F_{1,6} = 0.01$, $P = .93$) or a time by temperature interaction ($F_{5,30} = 0.10$, $P = .79$). A main effect for time was observed. Participants had a higher pace at 30 minutes than at all other time points (t_{13} range, –4.00 to –4.60, $P \leq .002$) (Figure 4B).

DISCUSSION

We had 2 main findings. First, ingestion of 900 mL of cold (2°C) fluid over 30 minutes (ie, –35 to –5 min) of pre-exercise rest produced a mean 0.4°C reduction in pre-exercise T_{rec} and resulted in lower T_{rec} during exercise. Therefore, we observed a precooling effect consistent with the magnitude associated with less practical methods.[1,2] Second, self-paced endurance performance in the heat was improved after this procedure. Cold-fluid ingestion potentially is a practical precooling method, and researchers should further investigate its utility in the field and its effectiveness against or as a complement to existing methods.

Precooling Effect

In our study, the mean precooling effect of 0.4°C over 30 minutes (ie, –35 to –5 minutes) is consistent with the finding of Lee et al,[5] who observed a mean reduction of 0.5°C in T_{rec} in 8 male participants over 30 minutes with a very similar cold-fluid strategy. In our study, differences between conditions became evident at 5 minutes of exercise, whereas Lee et al[5] observed differences in T_{rec} before exercise. The volume and composition of fluid ingested in our study were identical to those in the study by Lee et al[5] (ie, 900 mL, comprising 720 mL of water and 180 mL of sugar-free cordial), with only slight differences in temperature (ie, 2°C in our study and 4°C in the study by Lee et al[5]) and timing of ingestion (ie, 300 mL at –35, –25, and –10 minutes in our study and –30, –20, and –10 minutes in the study by Lee et al[5]) between studies. Our findings confirm the original observations of Lee et al[5] that cold fluid ingested over 30 minutes of pre-exercise rest can reduce T_{rec} during exercise. Moreover, pre-exercise ingestion of cold fluid alone without further ingestion during exercise resulted in lower T_{rec} during exercise. The differences in T_{rec} between conditions that became evident at 5 minutes of exercise persisted until 25 minutes. This finding appears to support the hypothesis by Lee et al[5] that pre-exercise cold-fluid ingestion alone without continued provision of cold fluid during exercise can reduce exercising T_{rec} and improve performance in the heat.

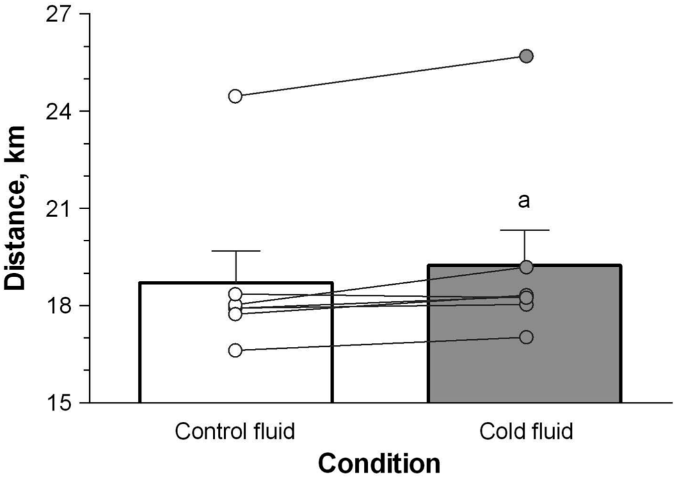

Figure 3. Distance cycled in 30 minutes after ingestion of 37°C (control) or 2°C (cold) fluid. [a]Indicates a greater distance cycled during the cold fluid than the control-fluid trial ($P = .03$). Values are mean ± SEM. Lines represent individual responses to the 2 treatments.

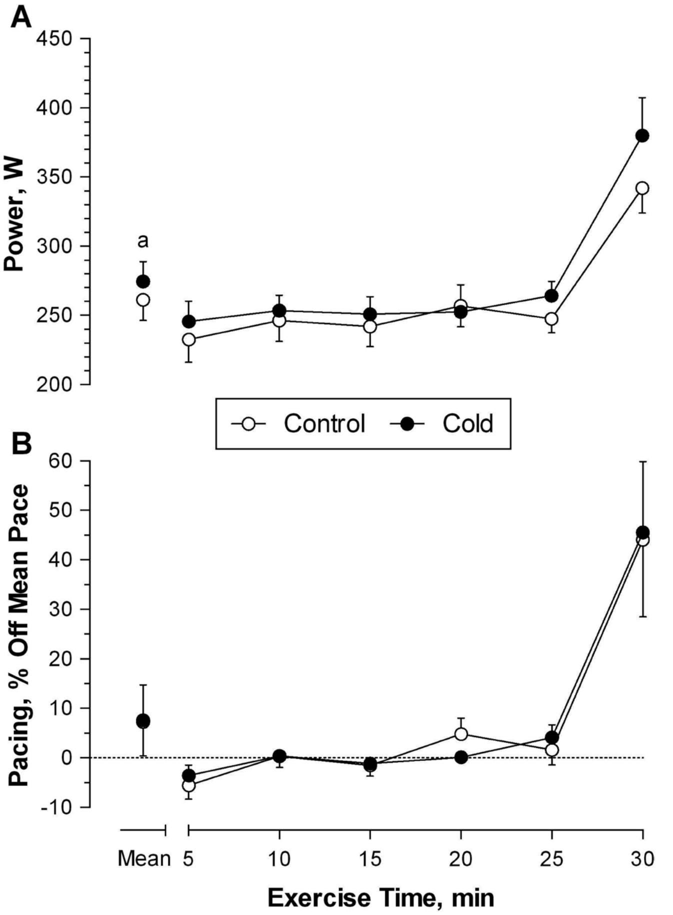

Figure 4. A, Power output during the 30-minute time trial. B, Pacing during the 30-minute time trial. [a]Indicates a higher mean power during the cold fluid than the control-fluid trial ($P = .05$). Values are mean ± SEM.

Ergogenic Effect

Our finding of a 2.8% (540 m) increase in distance cycled in 30 minutes supports an ergogenic effect of precooling for endurance performance in temperate to hot environmental conditions.[11–21] Direct comparisons with the magnitude of ergogenic effect observed in previous studies are limited because authors of only 2 studies[3,4] used the same protocol as we did, and only Kay et al[4] used the same mode of exercise. Kay et al[4] observed a 6.0% (900 m) improvement in performance when using an identical exercise protocol after 60 minutes of cool-water immersion, and Booth et al[3] observed a 4.2% improvement in distance run in 30 minutes after 60 minutes of cool-water immersion. Although these improvements are slightly higher than our findings, our effect does fall within the range of improvement commonly observed for self-paced exercise performance after precooling.[11,15,16,19] For example, Arngrimsson et al[16] observed a 1.1% (13-second) improvement in running time (approximately 19 minutes) for 5 km when participants wore cooling vests during a 38-minute warmup. Quod et al[19] observed a 3.8% (42-second) improvement in time to complete a fixed amount of work during self-paced cycling (approximately 18 minutes) when exercise was preceded by 30 minutes of cool-water immersion and 40 minutes of wearing a cooling vest before a 20-minute warmup. Hessemer et al[11] observed a 6.8% increase in mean work rate during 1 hour of self-paced cycling after 1 hour of cold air (approximately 0°C) exposure. Cotter et al[15] observed a 16% improvement in mean work rate during 15 minutes of self-paced cycling after participants wore ice vests and were exposed to cold air for 45 minutes and a 17.5% improvement after participants wore ice vests, were exposed to cold air, and had direct thigh cooling for 45 minutes. Recently, Duffield et al[20] reported an 11.2% improvement in mean power that corresponded with an estimated 7% increase in distance cycled during a 40-minute cycling time trial after 20 minutes of lower body immersion in cold (14°C) water. In the context of these studies, our data indicate that pre-exercise ingestion of cold fluid exerts a small but positive effect on self-paced performance of endurance exercise in environmental heat.

Mechanisms of Action

The mechanism or mechanisms for the observed ergogenic effect could not be established fully in our study. The reduction in T_{rec} during exercise suggested that a reduction in body temperature during exercise was associated with improved performance. The distribution of work rate (ie, pacing) was not different between conditions, but a subtle increase in work rate occurred across the whole time trial. The superior performance and therefore work rate after cold-fluid ingestion was achieved with similar T_{sk}, heart rate, blood lactate, and perceptual responses. Increased fluid availability through elevated rates of gastric emptying or intestinal absorption appears to be an unlikely mechanism. Cold fluids have been demonstrated to empty at both faster[22] and slower[23] rates than warm fluids. A lower body temperature before or during exercise might have facilitated the adoption of a higher work rate in the cold-fluid trial that was achieved with cardiovascular, metabolic, and perceptual responses similar to those of the control-fluid trial.

The final T_{rec} achieved in the cold-fluid (38.1 ± 0.3°C) and control-fluid (38.6 ± 0.5°C) trials revealed a modest level of hyperthermia that was well below the range (ie, 39.5–40.4°C) typically associated with exhaustion in trained athletes during laboratory cycling in the heat.[14] Therefore, precooling did not appear to exert an ergogenic effect by preventing an extreme level of hyperthermia in the cold trial versus the control trial. Nevertheless, the debilitating effect of environmental heat on self-paced endurance performance is evident even at modest levels of hyperthermia (eg, <38.5°C).[24,25] Investigators[26,27] using passive heating protocols revealed progressive reductions in voluntary isometric activation and maximal voluntary contractions with progressive hyperthermia ranging from 37.4°C to 39.6°C. Therefore, a lower core temperature would be beneficial in offsetting central fatigue even at modest levels of hyperthermia. Reductions in cardiovascular and perceptual strain (evidenced in our study as an equivalent strain despite a higher work rate) also could contribute to improved performance.[28]

Because masking the large temperature difference of ingested fluid (ie, 2°C versus 37°C) was impossible, an explanation for the improved performance with cold fluid is a potential placebo effect. Alternatively, stimulation of oral thermal receptors by cold fluid might have provided a cooling sensation that was interpreted as beneficial for subsequent performance in the heat. Interestingly, Mündel and Jones[29] observed that, during cycling to exhaustion at 65% $\dot{V}O_2$max in the heat, mouth swilling at 10-minute intervals with a menthol solution versus an orange-flavored control (both at 19°C) improved exercise capacity in association with hyperventilation and a reduction in central (cardiopulmonary) perceived exertion. The authors suggested that menthol stimulation of oral thermal receptors provided a pleasant cooling sensation that reduced the sense of effort and improved exercise capacity. Such findings suggest a complex integration of physiologic and perceptual systems in the regulation of exercise performance in the heat.

Potential Disadvantages

Achieving a precooling effect was consistent with beneficial physiologic and performance adaptations, but the method was associated with some minor negative consequences. With the cold-fluid trial, thermal comfort was reduced during the pre-exercise period to a mean of 2.3 units (2 indicates *too cool*) on the Bedford scale; 1 person began shivering; and the proportion of volunteers urinating immediately before exercise (ie, 86% versus 43%) with the control-fluid trial was increased, but mean urine volume remained unchanged. Lee et al[5] also observed a reduction in mean thermal sensation from +1 to –2 (indicating *some areas of body feel cold*) on a scale ranging from –10 (indicating *unbearable cold*) to +10 (indicating *unbearable heat*) after cold-fluid ingestion at rest but did not observe increased urination. Researchers should investigate whether these minor negative consequences observed in the laboratory translate into meaningful detrimental effects for the precompetition preparation of athletes in the field.

Future Directions

Although researchers might want to compare the effects of cold-fluid ingestion and established methods of precooling (eg, water immersion, cold air, ice vests), examining the combined effects of cold-fluid ingestion and methods offering high practical value for adoption by athletes in the field, such as cooling vests, might be more fruitful.[30] Cold-fluid ingestion offers high practical value because of its simplicity and because fluid intake is an established part of the acute (ie, <1 hour) preparation of athletes before competition in heat.[31] The method is useful to the scientist, athletic trainer, and athlete because the composition of the fluid can be manipulated. We showed that flavored water was effective, and manipulating the carbohydrate, electrolyte, or caffeine content of the fluid might provide additional or synergistic ergogenic benefits.[31] The volume of fluid ingested was well tolerated. However, we do not know whether this volume of fluid is well tolerated during weight-bearing oscillatory activity, such as running. The subsequent influence on ad libitum fluid intake and on fluid and electrolyte balance also should be determined.[32]

Precooling with fluid also offers the possibility of adding ice to the fluid to increase the specific heat capacity of the substance when ingested.[21] The specific latent heat of fusion needed for converting ice to water is large (334 kJ/kg), offering greater potential as a heat sink. Siegel et al[21] demonstrated that when their 10 male participants ingested approximately 600 mL of ice slurry, pre-exercise T_{rec} was reduced by 0.66±0.14°C, and run time to exhaustion in 34°C heat at an intensity corresponding to the ventilatory threshold was increased by 19±6% when compared with an equivalent volume of cold (4°C) fluid. The authors reported headaches attributable to ice-slurry ingestion (sphenopalatine ganglioneuralgia) in 3 of the 10 participants. Again, researchers need to investigate whether minor negative consequences observed in the laboratory translate into meaningful detrimental effects for the precompetition preparation of athletes in the field.

The ecological validity of our study might be limited by the use of an inappropriately low facing air velocity (ie, 3.2 m/s) compared with the expected outdoor air velocity at the given intensity (ie, 10.7 m/s). Saunders et al[33] reported that core temperature, heart rate, sweat rate, and perceived exertion were not different between air velocities of 2.8 m/s (9.9 km/h) and the more appropriate 9.3 m/s (33 km/h) during 2 hours of cycling at 60% peak power in a 33°C and 59% relative humidity environment. However, T_{sk} was elevated at 2.8 m/s.[33] Therefore, with a more appropriate air velocity in our study, skin temperature and body temperature probably would have been lower in both conditions, and this might have reduced the efficacy of our intervention. Further research is needed to test the efficacy of our intervention in laboratory studies using more realistic air velocities or studies undertaken in the field.

CONCLUSIONS

Pre-exercise ingestion of cold fluid was demonstrated as a simple, effective precooling method. The method has practical value, making it suitable for application at athletic venues in the acute preparation of athletes before training or competition in environmental heat.

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