

Effect of a 5-min cold-water immersion recovery on exercise performance in the heat

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ABSTRACT

Background This study examined the effect of a 5-min cold-water immersion (14°C) recovery intervention on repeated cycling performance in the heat.

Methods 10 male cyclists performed two bouts of a 25-min constant-paced (254 (22) W) cycling session followed by a 4-km time trial in hot conditions (35°C, 40% relative humidity). The two bouts were separated by either 15 min of seated recovery in the heat (control) or the same condition with 5-min cold-water immersion (5th–10th minute), using a counterbalanced cross-over design (CP₁TT₁ → CWI or CON → CP₂TT₂). Rectal temperature was measured immediately before and after both the constant-paced sessions and 4-km timed trials. Cycling economy and V_{O₂} were measured during the constant-paced sessions, and the average power output and completion times were recorded for each time trial.

Results Compared with control, rectal temperature was significantly lower (0.5 (0.4)°C) in cold-water immersion before CP₂ until the end of the second 4-km timed trial. However, the increase in rectal temperature (0.5 (0.2)°C) during CP₂ was not significantly different between conditions. During the second 4-km timed trial, power output was significantly greater in cold-water immersion (327.9 (55.7) W) compared with control (288.0 (58.8) W), leading to a faster completion time in cold-water immersion (6.1 (0.3) min) compared with control (6.4 (0.5) min). Economy and V_{O₂} were not influenced by the cold-water immersion recovery intervention.

Conclusion 5-min cold-water immersion recovery significantly lowered rectal temperature and maintained endurance performance during subsequent high-intensity exercise. These data indicate that repeated exercise performance in heat may be improved when a short period of cold-water immersion is applied during the recovery period.

To maintain performance during sporting events held in hot environmental conditions, athletes must regulate their core temperature within a relatively narrow (37°–40°C) range.¹ Increases in core temperature of only 2°C above normal can increase the perception of fatigue and result in reduced exercise performance.^{2–3} Many team sports such as soccer require athletes to compete over prolonged periods (60–90 min), at relatively high intensities (ie, ~65% V_{O₂}max), separated into equal halves by a 10–15-min halftime break.⁴ Time–motion analyses of soccer indicate that both submaximal and sprint performance decrease during the second half of competition.^{4–5} When games are played in the heat, elevated core temperatures (>39°C) from the first half can increase the level of fatigue experienced during the second half of competition, leading to further

decreases in performance.⁶ Therefore, a strategy to reduce core temperature during halftime breaks (~15 min) could minimise the reduction in performance that is often observed during the second half.

The high specific heat of water (ie, the ability to absorb large amounts of heat before changing temperature), coupled with water's ability to be applied over a large surface area, makes cold-water immersion an effective method to rapidly reduce core body temperature.⁷ The effectiveness of cold-water immersion for decreasing core temperature and increasing the heat storage capacity of individuals during exercise has been quantified.^{8–9} For example, after 30 min of 14°C torso-only cold-water immersion, Marsh and Sleivert⁸ reported an average decrease in rectal temperature of 0.3°C during a 15-min exercise session. Additionally, Kay *et al*⁹ observed a significant increase (158 (13.1 W m²) vs 84 (8.8 W m²)) in heat storage capacity during 30 min of constant-paced cycling following 58 min of 25°C whole-body cold-water immersion, when compared with a control condition.

Despite the promise of using cold-water immersion recovery to improve exercise performance in the heat, controversy exists concerning its effectiveness.^{10–14} For example, Crowe *et al*¹⁰ and Schniepp *et al*¹³ reported a decrease in cycling sprint performance after a 15-min whole-body cold-water immersion (14°C) intervention. However, both of these studies were conducted in non-hyperthermic conditions (<27°C), which do not represent a practical scenario for applying a cold-water immersion intervention. Conversely, Yeargin *et al*¹⁴ showed that 12 min of whole-body cold-water immersion (14°C) after 90 min of running in the heat significantly reduced the time to complete a 2-mile running time trial compared with a control condition. It should be noted that the cold-water immersion periods (12–15 min) used for these studies were not of practical relevance and would not fit into a typical 15-min halftime break. In a study from our laboratory, 5 min of cold-water immersion (14°C) after an exhaustive bout of exercise in the heat resulted in similar end rectal temperatures compared with two longer immersion (10 and 20 min) durations (Peiffer *et al* 2007, unpublished observations). Therefore, we hypothesised that a 5-min cold-water immersion intervention applied during a 15-min recovery period would lower core temperature and attenuate the exercise performance reduction commonly observed during subsequent high-intensity exercise in the heat.

To test this hypothesis, the present study used a repeated cycling exercise model consisting of

25 min of constant-paced cycling at the power output equal to 65% $\dot{V}O_{2\max}$, followed immediately by a high-intensity 4-km (~6 min) cycling time trial. This simplistic cycling model was chosen to examine how 5 min of cold-water immersion might affect rectal temperature and both submaximal and maximal exercise performance under hot conditions (35°C and 40% relative humidity).

METHODS

Subjects

Ten well-trained male cyclists (age: 35 (7 years), height: 183 (7 cm), mass: 80.3 (9.7 kg), $\dot{V}O_{2\max}$: 60.5 (4.5 ml kg⁻¹ min⁻¹), peak power: 441 (32) W) volunteered to participate in this study. All subjects had been training for at least 3 years and had a weekly training volume that was greater than 250 km week⁻¹. The current sample size was selected based on a power analysis ($\alpha = 0.05$ and power = 80%) using the SD of rectal temperature responses to cold-water immersion from a previous investigation.¹⁵ Subjects were given written instructions of the possible risks and benefits of their participation in the study and gave signed informed consent before study commencement. The subjects were required to complete one graded exercise test, and two experimental sessions separated by 4–7 days. The study was approved by the Human Research Ethics Committee at Edith Cowan University.

Graded exercise test

During the initial testing session, subjects completed a graded exercise test on an electromagnetically braked Velotron cycle ergometer (Racermate, Seattle, Washington, USA) at normal room temperature (22°C). The subjects began the graded exercise test at 70 W, and increases of 35 W min⁻¹ were applied until volitional fatigue. During exercise, average oxygen consumption ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) were recorded at 30-s intervals using a Medgraphics CPX gas analyser system (Medical Graphics, St Paul, Minnesota, USA). The power output associated with 65% of $\dot{V}O_{2\max}$ was used as the steady-state power output in the subsequent experimental sessions.

Experimental sessions

During the two experimental sessions, subjects completed 25 min of constant-pace cycling on the Velotron cycle ergometer at a power output (255 (22) W) that corresponded to 65% of $\dot{V}O_{2\max}$ in an environmental chamber maintained at 35°C and 40% relative humidity. The intensity and duration of the constant-pace session were selected to provide an adequate stimulus to increase core temperature² and induce fatigue.³ The first constant-pace session was followed 2 min later by a 4-km cycling time trial. Subjects were not permitted to warm-up before either the constant-pace session or the 4-km time trial. The temperature and relative humidity selected for this study were based on pilot work that determined the hottest conditions that subjects could tolerate and still finish the required workload. After the first time trial, subjects remained in the environmental chamber for 15 min, and in a counter-balanced cross-over order, were assigned to either a cold-water immersion or a control condition. In the cold-water immersion condition, subjects were immersed in water (14°C) for 5 min between the 5th and 10th minutes of the 15-min recovery period. To isolate the recovery benefits of cold-water immersion, passive sitting occurred before and after the cold-water immersion period. During the control condition, subjects were

seated for the entire 15 min in the 35°C heat chamber. After the 15-min recovery period, subjects performed a second 25-min constant-pace cycling session (65% $\dot{V}O_{2\max}$) followed by a second 4-km time trial. To simulate typical outdoor convective environmental conditions, a custom-built fan (Kinetic Performance Technologies, Mitchell, ACT, Australia) was placed at a distance of 1 m in front of the bicycle to maintain a constant wind velocity of 32 km h⁻¹ at the point of the cyclist for all cycling trials. Subjects' rating of perceived exertion (RPE)¹⁶ was recorded at baseline and after both the constant-pace sessions and 4-km time trials.

Cold-water immersion

During the 5-min cold-water immersion, subjects were submerged in an inflatable water bath, in a seated position to the mid-sternal level, wearing only their cycling shorts. Water temperature was maintained at a constant 14°C by a specially designed water refrigeration unit (iCool Portacoolery, Gold Coast, Australia). The water temperature selected for this study (14°C) was chosen as it appears as the most commonly used water temperature in previous cold-water immersion studies^{12–14 17 18} and is effective at lowering body temperature and is tolerable for most subjects.

Rectal temperature

Before exercise, a disposable rectal thermometer (Monatherm Thermistor, 400 Series; Mallinckrodt Medical, St Louis, Missouri, USA) was self-inserted by the subject to ~12 cm past the anal sphincter. Rectal temperature was recorded throughout the experiment at a frequency of 1 Hz using a data-logger (Grant Instruments, Shepreth, UK). For simplicity and statistical analysis, rectal temperature data are presented as the average of a 60-s sample measured before and immediately after the first constant-pace session and 4-km time trial and before and immediately after the second constant-pace session and 4-km time trial.

Exercise economy during the constant-pace sessions

Breath-by-breath measurements of $\dot{V}O_2$ were recorded throughout the first and second constant-pace sessions using a Medgraphics CPX gas analyser system. To avoid additional oxygen consumption not related to the exercise, subjects were required to maintain a comfortable cadence >70 rpm, and to refrain from standing during the measurement period; cadence was recorded for later analysis. Exercise economy (W l⁻¹ o₂ min⁻¹) during the constant-pace session was calculated using the following equation:

$$\text{Economy} = \text{Workload}/\dot{V}O_2$$

where workload was the applied resistance (W), and $\dot{V}O_2$ was measured in l min⁻¹.

The 4-km time trial performance

Subjects began the 4-km time trial from a standing start and were instructed to complete the required distance in the shortest time possible. During the time trial, external feedback was limited to the distance completed. At the start of the exercise, a timer was started, and the total time to finish the 4-km was recorded. Power output was calculated via an algorithm within the Velotron software and sampled at a rate of 1 Hz. The average power output from the start to the finish of the time trial was calculated and used for later analysis.

Statistical analysis

Changes in rectal temperature, RPE, Vo_2 , economy, cadence, power output and completion time were analysed using a two-way repeated measures analysis of variance (ANOVA). Significant main effects and interactions were analysed using paired *t* tests with Bonferroni adjustments for multiple comparisons. Changes in Vo_2 , economy and cadence between the first and second constant-pace sessions, and the completion time and average power output during the first and second time trials, were also analysed by a one-way ANOVA for each condition separately. Statistical analyses were conducted using SPSS data analysis software (SPSS V.15). The significance level was set at $p = 0.05$, and all data are presented as mean (SD).

RESULTS

Rectal temperature

Figure 1 shows the change in rectal temperature over time. A significant ($p < 0.01$) interaction was found between the cold-water immersion and control conditions. Compared with the control condition, rectal temperature was significantly lower for all time points in the cold-water immersion condition after the 15-min recovery period. Following the 15 min of recovery, rectal temperature decreased from $38.6 (0.4)^\circ\text{C}$ to $38.2 (0.2)^\circ\text{C}$ for the cold-water immersion condition, but no change in rectal temperature was found ($38.6 (0.4)^\circ\text{C}$ vs $38.6 (0.5)^\circ\text{C}$) for the control condition. Nevertheless, the magnitude of increase in rectal temperature from before the second constant-pace session to after the second 4-km time trial was not significantly different ($p = 0.07$) between the cold-water immersion ($0.5 (0.2)^\circ\text{C}$) and control ($0.6 (0.1)^\circ\text{C}$) conditions (fig 1).

Exercise economy during constant-pace sessions

No differences in Vo_2 were found between the first and second constant-pace sessions in the cold-water immersion ($3.2 (0.3 \text{ l min}^{-1})$ and $3.2 (0.3 \text{ l min}^{-1})$, respectively) or control ($3.3 (0.3 \text{ l min}^{-1})$ and $3.2 (0.3 \text{ l min}^{-1})$, respectively) conditions. Similarly, the exercise economy was not different between bouts in either the cold-water immersion ($75.2 (4.2 \text{ W l}^{-1} \text{ min}^{-1})$ and $75.3 (4.3 \text{ W l}^{-1} \text{ min}^{-1})$, respectively) or control ($74.1 (4.2 \text{ W l}^{-1} \text{ min}^{-1})$ and $76.1 (5.1 \text{ W l}^{-1} \text{ min}^{-1})$, respectively) conditions. A significant interaction ($p < 0.01$)

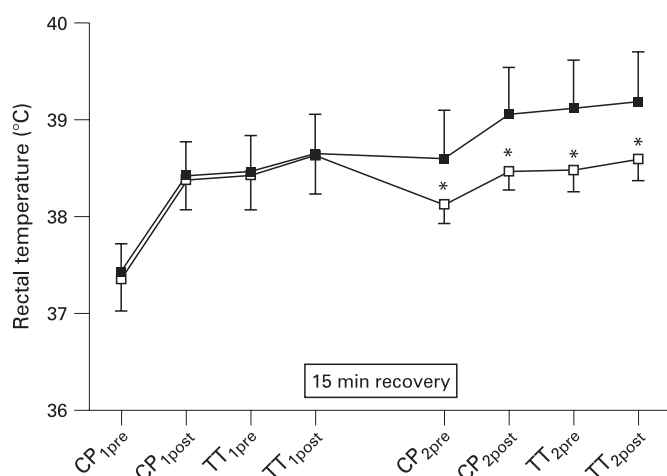


Figure 1 Rectal temperature measured before (CP_{1pre}, CP_{2pre}) and immediately after (CP_{1post}, CP_{2post}) the 25-min constant-pace cycling phase and before (TT_{1pre}, TT_{2pre}) and immediately after (TT_{1post}, TT_{2post}) the 4-km time trial in the cold-water immersion (?) and control (i) conditions. *Significantly ($p < 0.05$) different between conditions.

was evident for cadence. During the second constant-pace session, cadence was significantly higher ($p < 0.05$) in the cold-water immersion (88 (6 rpm)) compared with the control (85 (7 rpm)) condition.

The 4-km time trial performance

The 4-km time trial completion time increased significantly ($p < 0.05$) from the first to second time trial for the cold-water immersion (+6.0 (5.4 s)) and control (+24 (12 s)) conditions (fig 2A). A significant interaction ($p < 0.01$) was observed between the cold-water immersion and control conditions. The average completion time for the second 4-km time trial was significantly less ($-18.0 (11.5 \text{ s})$; $p < 0.05$) after cold-water immersion compared with the control condition (fig 2A).

Average power output during the first and second 4-km time trials are shown in fig 2B. There was a significant ($p < 0.05$) decrease in average power output from the first to second time trial in the control ($-20 (6.0)\%$) and cold-water immersion ($-3.0 (3.0)\%$) conditions. A significant interaction ($p < 0.01$) was observed between conditions, with a greater ($p < 0.05$) average power output recorded during the second time trial for cold-water immersion compared with the control condition (fig 2B).

Rating of perceived exertion

Table 1 shows the RPE measured following both constant-pace and time trial exercise phases. Compared with the first constant-pace session, RPE was significantly greater after the second constant-pace session in the control condition; however, no difference was observed in the cold-water immersion condition. A significant ($p < 0.01$) interaction effect was also found, identifying that RPE was significantly ($p < 0.05$) lower after the second constant-pace session for cold-water immersion compared with the control condition.

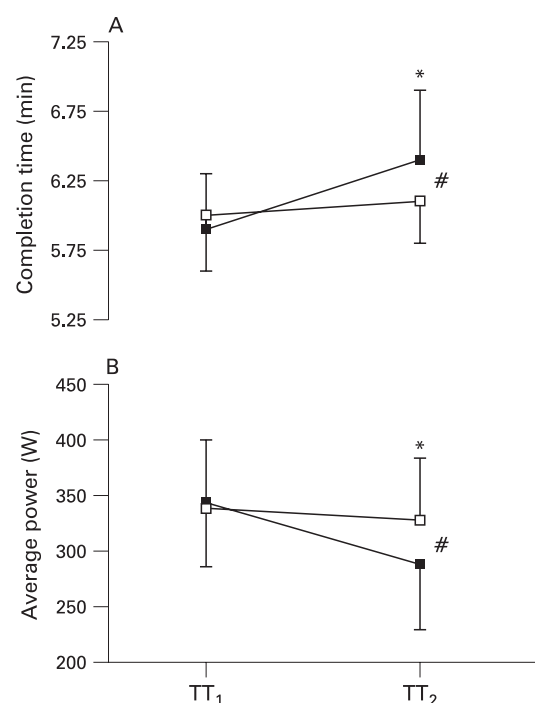


Figure 2 Completion time (A) and average power (B) for the first (TT₁) and second (TT₂) 4-km time trial measured in the cold-water immersion (?) and control (i) conditions. *Significantly ($p < 0.05$) different from control; #significantly ($p < 0.05$) different than TT₁ in both conditions.

Table 1 Comparison between control (CON) and cold-water immersion (CWI) conditions for average ratings of perceived exertion after the first (CP₁) and second (CP₂) constant-pace cycle session, and the first (TT₁) and second (TT₂) 4-km time trial

	CP ₁	TT ₁	CP ₂	TT ₂
CON	13.2 (1.3)	18.0 (0.7)	16.8 (1.1)‡	18.9 (1.1)
CWI	12.8 (1.1)	18.5 (1.3)	14.3 (2.3)*	18.2 (1.1)

Note, data are 6–20 scale Borg units for rating of perceived exertion.¹⁶

*Significantly ($p < 0.05$) different from the CON condition.

‡Significantly ($p < 0.05$) different from CP₁.

DISCUSSION

The main findings of the present study were that: (1) compared with the control condition, cold-water immersion significantly lowered rectal temperature after the recovery phase and throughout the second 4-km time trial; (2) no significant differences in Vo_2 or economy were observed between the constant-pace phases for both conditions; and (3) cold-water immersion resulted in a significantly higher average power output and a significantly shorter completion time during the second 4-km time trial compared with the control condition.

Cold-water immersion applied after a bout of exercise in the heat can decrease core temperature at a rate that is faster than heat loss occurring under normal convective conditions.^{14 15 17 19} Most studies that have examined this aspect of post-exercise cold-water immersion have used cold-water immersion durations that ranged between 12 and 15 min.^{14 15 17} These durations do not accurately represent a practical cold-water immersion duration that could be applied during a common half time scenario (ie, 15 min). In our study, 5 min of cold-water immersion resulted in a significant reduction in rectal temperature at the start of the second constant-pace session, and this reduction persisted until completion of the second time trial (fig 1). These results indicate that immersing hyperthermic ($>38.5^\circ\text{C}$) athletes in cold water for 5 min after exercise can significantly decrease rectal temperature.

Exposure to a cold-water immersion intervention can rapidly decrease muscle temperature and muscular force output.^{20 21} Under these cooler muscle temperatures, additional motor units must be recruited to produce similar levels of muscular force output.²² These additionally recruited motor units must arise from the less efficient type II muscle fibres, resulting in a decreased economy of motion.²³ For these reasons, we hypothesised that after our cold-water immersion intervention, oxygen consumption would be elevated, and cycling economy would be lowered during the second constant-pace cycling session. While we did not directly measure motor unit recruitment levels, the fact that Vo_2 was not different between conditions suggests that motor unit recruitment levels were not significantly altered after the cold-water immersion intervention.²³ There was however, a significant ($p < 0.05$) increase (3.0 (3.0)%) in cycling cadence during the second constant-pace session after cold-water immersion. The increase in pedalling rate was likely a consequence of the cooler core body temperatures (fig 1), resulting in a lowered perception of fatigue.²⁴ To our knowledge, this study is the first to report a change in cycling cadence after a post-exercise cooling intervention.

Elevations in core temperature can increase thermal fatigue leading to a reduction in exercise performance.^{2 3 25 26} Indeed, during constant-pace cycling in the heat, Nybo and Nielsen²⁴ reported a strong correlation ($r = 0.95$) between fatigue-related decreases in frontal cortex beta-wave activity and increases in RPE. In our study, RPE during the second constant-pace session was significantly lower after cold-water immersion compared

with the control condition (table 1). This reduced RPE paralleled the reduction in rectal temperatures found after the recovery intervention (fig 1). During exercise in the heat performed at a fixed RPE level, exercise intensity is decreased in response to the need to reduce internal heat storage accumulation.²⁷ In the present study, the lower RPE value observed before the second time trial in the cold-water immersion condition (table 1) likely permitted the higher exercise intensity shown during the second 4-km time trial (fig 2).

Yeargin *et al* (2006) showed that 15 min of cold-water immersion (14°C) after 90 min of running in the heat can significantly improve subsequent 2-mile running time trial performance. The improved running performance occurred with a mean rectal temperature that was 0.5°C lower than in the control condition. We found a comparable 0.6°C reduction in rectal temperature before the second time trial after our cold-water immersion intervention. These findings imply that a core temperature reduction of approximately 0.5°C may be needed to elicit improvements in performance under hot conditions. Future research is required to ascertain the smallest worthwhile difference in rectal temperature needed for improved endurance performance in the heat.

While findings from the present study are promising for practitioners, the findings are not without limitations. Our inability to blind subjects to the recovery treatment highlights an intrinsic limitation of cold-water immersion research. While the lower rectal temperatures found in the cold-water immersion condition before the second time trial were the most plausible cause of the performance improvements, a placebo effect cannot be ruled out. Nevertheless, the improved

What is known on this topic

- ▶ During exercise in the heat, increases in rectal temperature significantly reduce exercise performance.
- ▶ Cold water immersion recovery interventions used after exercise in the heat can significantly lower rectal temperature.
- ▶ Fifteen minutes of 14°C cold water immersion after exercise in the heat can improve subsequent exercise performance.

What this study adds

- ▶ Five minutes of cold water immersion during a 15 minute recovery session can significantly lower rectal temperature.
- ▶ Subsequent submaximal exercise economy is not affected by a 5 minute cold water immersion recovery intervention.
- ▶ High-intensity endurance performance in the heat can be enhanced after a 5 minute cold water immersion recovery intervention.

performance shown after the cold-water immersion intervention should be of interest to practitioners regardless of the underpinning mechanisms. Finally, while the present study used a simplistic cycling model to examine the submaximal and maximal exercise response, future studies are needed to confirm the effectiveness of a cold-water immersion intervention using a protocol that mimics team sport performance.

In summary, our data indicate that 5 min of cold-water immersion during a 15-min recovery session can decrease rectal temperature and attenuate the decline in high-intensity exercise performance without affecting submaximal economy of motion in hot environmental conditions. Athletes performing multiple exercise bouts in hot environmental conditions should consider using a cold-water immersion intervention to reduce the deleterious effects that hyperthermia has on exercise performance.

Competing interests None.

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