

Comparative effects of head cooling, a cooling vest, and ice ingestion on running performance and psychophysiological strain in a hot outdoor environment

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Abstract:

Endurance performance is impaired in hot environments due to increased heat strain and the associated physiological and perceptual stress. Cooling strategies may help mitigate these effects, but comparative data under ecologically valid outdoor conditions remain limited. Therefore, this study compared the effects of head cooling, a cooling vest, and crushed ice ingestion on 5-km time-trial performance, thermoregulatory and perceptual responses, and cognitive function in the hot, humid outdoor conditions. Fourteen ($n = 14$) moderately trained men (22.3 ± 2.4 years) completed four randomised, counterbalanced crossover trials in hot outdoor environments (WBGT; $\sim 33^{\circ}\text{C}$, 60% RH): (i) head cooling (20 minutes before the run) plus ice ingestion (every 5 minutes during the run); (ii) crushed ice ingestion ($7.5 \text{ g} \cdot \text{kg}^{-1}$, 20 minutes before the run) plus ice ingestion (every 5 minutes during the run); (iii) cooling vest (20 minutes before the run) plus ice ingestion (every 5 minutes during the run); and (iv) control (no cooling). Primary outcomes were 5-km completion time and cognitive performance (Digit Symbol Substitution Test). Body temperature, heart rate, rating perceived exertion, and thermal sensation were measured at specific intervals across the experimental protocol. Result indicated that all cooling conditions improved 5-km performance compared to control ($p \leq .05$), with no differences among cooling strategies. Body temperature showed a significant interaction of treatment $\times$ time ($p \leq .05$); with ice ingestion and cooling vest resulted in lower body temperature than control from mid-exercise onwards ($p \leq .05$). Cognitive performance demonstrated a time effect ($p < .05$), but no treatment or interaction effects were reported. Heart rate, rating perceived exertion, and thermal sensation did not differ in their time-course across conditions. The observed outcomes suggested that cooling interventions were able to enhance running performance in hot outdoor environments. Of these, ice ingestion and cooling vest strategies were apparent to have the greatest thermoregulatory effects.

Key Words: Thermal strain; Pre-cooling; Per-cooling; Endurance exercise; Heat mitigation; Cognitive function

Introduction

Exercise in hot, humid environments can impair athletic performance through increased body temperature, cardiovascular strain, and perceptual discomfort, which collectively reduce the ability to sustain intensity during self-paced exercise (Cowe et al., 2025; Mazalan et al., 2022b; T. Naito et al., 2022; Nybo et al., 2014). Contemporary models of performance in the heat emphasise behavioural regulation, where athletes adjust their pacing in response to increased thermal strain and perceived exertion to maintain physiological homeostasis (Nybo et al., 2014; van de Kerkhof et al., 2024). In addition to impairing physical capacity, heat stress may also compromise cognitive function, which can influence pacing regulation, decision-making, and task execution during self-paced exercise in hot conditions (Donnan et al., 2022; Racinais et al., 2015; Schmit et al., 2017; Wen et al., 2022). Therefore, since self-paced performance depends on continuous monitoring and adjustment of effort in response to internal and environmental information, examining cognitive components alongside physiological and perceptual responses may provide a more comprehensive understanding of how heat mitigation strategies, such as cooling, support pacing regulation and exercise performance under thermal stress (Periard et al., 2021; Tyler et al., 2015; van de Kerkhof et al., 2024).

Cooling strategies can be applied through internal and external modalities, each targeting different physiological and perceptual pathways in supporting performance. These strategies may improve performance by reducing body temperature, delaying the rise in thermal strain, increasing heat storage capacity, lowering skin temperature, improving thermal comfort, or reducing perceived heat stress (Bongers et al., 2017; Cowe et al., 2025; Stevens et al., 2025; van de Kerkhof et al., 2024). Cooling may be administered before exercise as pre-cooling or during exercise as per-cooling, depending on the intended physiological effect and practical context (Cowe et al., 2024; Cowe et al., 2025; Mazalan et al., 2022a; Roriz et al., 2024; Wen et al., 2022). In applied

sporting environments, the feasibility of cooling strategies is particularly important, including factors such as cost, portability, logistics, ease of application, and athlete acceptance (Roriz et al., 2023; Schraner et al., 2017; Wen et al., 2022). Thus, comparing practical and field-feasible cooling methods may help identify effective strategies for maintaining exercise performance during real-world heat exposure.

Head cooling, cooling vest application, and crushed ice ingestion represent distinct cooling approaches with different mechanisms of action. Head cooling targets a highly thermosensitive region close to the brain's thermoregulatory centres that may reduce thermal discomfort (Cao et al., 2022; Desroches et al., 2024; Mazalan et al., 2021). Cooling vest application provides external torso cooling over a relatively large surface area and may attenuate thermal and cardiovascular strain (Chaen et al., 2019; Fernández-Lázaro et al., 2023). In contrast, crushed ice ingestion provides internal cooling and may directly influence internal heat balance more by lowering thermal load and increasing heat storage capacity (Andrade et al., 2024; Mazalan et al., 2022b; Naito et al., 2022). Previous laboratory-based studies have demonstrated that head cooling and ice ingestion may support cognitive and physical performance during exercise in the heat, while cooling vest interventions have also shown effectiveness in reducing thermoregulatory and cardiovascular strain (Fernández-Lázaro et al., 2023; Mazalan et al., 2021, 2022a, 2022b). Building on this evidence, these cooling approaches may enhance exercise performance by reducing thermal strain and perceptual discomfort, thereby allowing athletes to maintain a higher self-selected pace in hot conditions (Kay et al., 1999; Mazalan et al., 2022a; van de Kerkhof et al., 2024).

Although cooling strategies have demonstrated performance benefits during exercise in the heat, head cooling, cooling vest application, and crushed ice ingestion have often been examined separately. Direct comparisons of these strategies under practical outdoor conditions remain limited (Chaen et al., 2019; Desroches et al., 2024; Mazalan et al., 2021; Naito et al., 2020; Saldaris et al., 2020). Furthermore, cognitive function is less frequently examined together with physical performance, thermoregulatory responses, and perceptual responses, despite evidence that heat stress may affect cognitive processing during exercise (Cowe et al., 2025; Donnan et al., 2021; MacLeod et al., 2018; Nybo, 2012). Therefore, studies integrating performance, physiological, perceptual, and cognitive outcomes in ecologically valid outdoor environments are needed to clarify the practical value of cooling strategies for exercise in the heat.

Accordingly, the present study addresses an important applied problem: identifying practical cooling strategies that can be implemented in real-world hot and humid outdoor environments. This research was needed because existing evidence has not fully clarified whether different cooling modalities produce comparable benefits when applied under field-based self-paced running conditions (Cowe et al., 2024; Mazalan et al., 2022a; Spannagl et al., 2023). Moreover, comparing these strategies within the same experimental design allows clearer interpretation of their relative practical value and potential application during endurance exercise in the heat. Evidence from such conditions may better inform athletes, coaches, and practitioners on feasible pre- and per-cooling approaches to reduce heat strain and support endurance performance.

The purpose of this study was to compare the effects of head cooling, cooling vest application, and crushed ice ingestion as pre-cooling strategies, while standardising per-cooling through ice ingestion across all cooling trials, on 5-km time-trial performance, thermoregulatory responses, perceptual responses, and cognitive function in hot and humid outdoor conditions. Using a randomised, counterbalanced crossover design, this study assessed performance, thermoregulatory, perceptual, and cognitive outcomes across cooling and control conditions. It was hypothesised that cooling interventions would improve 5-km running performance compared with the control condition by attenuating thermoregulatory strain, limiting the rise in body temperature, and helping participants maintain a higher self-selected running pace under hot and humid outdoor conditions.

Material & Methods

Participants

Fourteen active males (age: 22.29 ± 2.37 years; BMI 21.31 ± 1.85) volunteered for this study. All participants were moderately trained (engaging in aerobic exercise ≥ 3 times per week). Participants were excluded if they had an injury affecting running performance, any medical condition or medication known to affect thermoregulatory function or failed to comply with the experimental protocol. All participants were fully informed about the study procedures and the potential discomforts and risks prior to providing written informed consent.

Study Design

A randomised, counterbalanced, within-subject crossover design was applied for this study. Each participant completed four experimental conditions (HC: head cooling; IC: ice cooling; CV: cooling vest; CON: control) in a randomised order, with the sequence counterbalanced across participants to minimise order effects. Trials were separated by a 7-day washout period to ensure complete recovery and minimise carryover effect.

Experimental Procedure

Participants were instructed to refrain from tobacco, caffeine, alcohol, and other drugs; avoid strenuous physical activity for 24 h prior to each trial; and obtain ≥ 8 h sleep the night before testing. Additionally, participants were asked to arrive well-hydrated and maintain similar dietary intake prior to each visit.

All experimental trials were conducted outdoors at a 400-meter track in tropical, hot, humid environments. Environmental heat stress was monitored using a wet-bulb globe temperature (WBGT), with

temperature ~32-34°C and ~60% relative humidity across trials. Trials were conducted at the same time of day to reduce circadian effect in thermoregulatory responses.

Upon arrival at the outdoor stadium, urine specific gravity (USG) (JSCP-Uridens) was measured to assess participants' hydration status. After that, participants sat for 20 minutes to allow their body temperature to stabilise. During this period, baseline measures were obtained, including core temperature (T_c), heart rate (HR), thermal sensation (TS) and cognitive function. Participants wore standardised attire for all trials.

Following baseline assessments, participants underwent a 20-minute seated pre-cooling period according to the randomised trial condition: HC- participants wore a head cooling cap; IC- crushed ice ingestion; CV- participants wore a cooling vest; and CON- participants sat without any cooling intervention. T_c, HR and TS were measured at 10-minute intervals during the pre-cooling period.

After the pre-cooling period, participants' pre-exercise body mass was weighed, and they then completed a 5-km self-paced running time trial on a standard 400-meter outdoor track. Throughout the trial, participants controlled their own running pace to complete as fast as possible. Strong verbal encouragement was provided consistently in all conditions; however, they were not informed of their pace and time (aside from the laps remaining) to prevent bias. T_c, HR, TS and rating perceived exertion (RPE) were measured at standardised distance intervals during the run.

Per-cooling was standardised in all cooling trials where participants ingested crushed ice every 5 minutes during the exercise. In the control condition, no cooling technique was provided, and participants were allowed to drink plain water at the same time as the per-cooling intervention.

Immediately upon completion of the 5-km running time trial, post-exercise body mass was measured. T_c, HR, TS, RPE and the cognitive function were assessed again for post-exercise information.

Cooling Interventions

Pre-cooling

Head Cooling (HC): A commercial gel-based cooling cap (pre-cooled to ~0°C) was worn on the head for 20 minutes prior to the run. The cap covered the head and part of the neck. During the 20-minute head cooling session, participants sat resting in the stadium's shaded area. The cap was taken off right before the run started.

Ice Cooling (IC): A total of 7.5 g·kg⁻¹ of crushed ice (-1°C) was ingested in the 20 minutes before the run. This was divided into equal portions given every 10 minutes. Ice ingestion was administered in a shaded area at the stadium.

Cooling Vest (CV): Participants wore an ice cooling vest over the torso for 20 minutes prior to the run. The vest, covering the chest, abdominal area and upper back, was worn on a t-shirt while the participant rested in the stadium's shaded area.

Per-cooling

Participants received a standardised per-cooling intervention in all cooling conditions. During each 5-km running time trial, participants ingested ~100 mL of crushed ice (-1°C) every 5 minutes.

Control (CON): No cooling technique was administered. Participants rested for 20 minutes before the run, in the same shaded condition at the stadium. Participants were allowed to consume room-temperature water before and during the run, with the volume standardised to match the ice cooling protocol.

Measurements

Physical Performance: 5-km time trial performance.

The primary performance metric was the time required to finish the 5-km running time trial in hot environments.

Cognitive Performance: Digit Symbol Substitution Test (DSST).

DSST was used to measure processing speed and sustained attention (Bettcher et al., 2011). The test consisted of a standardised digit pairing with matching symbols. Participants were required to substitute the correct symbol for each digit as quickly and accurately as possible. The DSST was conducted pre-exercise before the pre-cooling period and again during the post-exercise recovery period. The main DSST outcome was the time required to complete the test with correct responses. To minimise learning effects, participants underwent several practice attempts during the familiarisation visit.

Physiological Measure: Core temperature (T_c) and Heart Rate (HR)

Core temperature (T_c) was measured using a non-invasive wearable heat-flux sensor (CORE Body Temperature Sensor; greenTEG AG, Switzerland) worn on the chest. The CORE system continuously monitored the core temperature derived from the heat-flux and skin temperature signals calculated via an embedded algorithm. This sensor reported acceptable test-retest reliability with a mean bias of ~ 0.02°C between identical trials (Verdel et al., 2021). Data from this wearable non-invasive device were treated as an estimate of internal heat strain. Heart rate was measured using a chest strap heart rate monitor (Polar, Finland). Core temperature and heart rate readings were taken at predetermined intervals prior to exercise, during the 5-kilometre time trial, and during recovery.

Perceptual Responses: Rating Perceived Exertion (RPE) and Thermal Sensation (TS)

Perceived exertion during the experimental trials was assessed using the 10-point Borg scale, ranging from 0 (no exertion at all) to 10 (maximal exertion) (Borg, 1970). Meanwhile, thermal sensation was measured using a 9-point ASHRAE scale ranging from -4 (very cold) to +4 (very hot), with 0 indicating neutral sensation.

Statistical analysis

Data is presented as mean $\pm$ standard deviation (SD). Treatment effects were analysed using repeated-measures ANOVA. 5-km time trial performance was analysed with a one-way repeated-measures ANOVA (condition). Tc, HR, RPE, TS and cognitive performance were analysed using two-way repeated-measures ANOVA (condition $\times$ time). Greenhouse-Geisser corrections were applied when sphericity was violated. Statistical significance was set at $p \leq 0.05$. Post-hoc comparisons with Bonferroni adjustments were made if significant effects were detected. All statistical analyses were performed in IBM Statistical Package for Social Sciences (SPSS) version 29.0 (SPSS Inc, USA).

Results*5-km time-trial performance*

A significant main effect of treatment was observed for 5-km time-trial running performance ($F(3,39) = 24.893$, $p < 0.001$, $\eta^2 = 0.657$). Mean completion times (min) were HC 24.29 ± 3.76 , IC 24.12 ± 3.52 , CV 24.61 ± 3.92 , and CON 25.95 ± 4.07 . Post-hoc Bonferroni-adjusted comparisons showed that time-trial performance was significantly faster in all cooling conditions compared with control. Specifically, completion time was reduced in HC vs CON (-1.654 min, $p < 0.001$, $d_z = 2.34$, 95% CI 1.51 to 3.17), IC vs CON (-1.821 min, $p < 0.001$, $d_z = 1.62$, 95% CI 0.79 to 2.45), and CV vs CON (-1.334 min, $p = 0.002$, $d_z = 1.32$, 95% CI 0.48 to 2.15). However, there were no differences between cooling conditions ($p > .05$), indicating comparable performance benefits across cooling modalities (Table I).

Table I. 5-km time-trial running performance

Condition	Mean $\pm$ SD	Comparison vs CON (mean difference, min)	p	Cohen's d_z
HC	24.29 ± 3.76	-1.654	$< .001^*$	2.34
IC	24.12 ± 3.52	-1.821	$< .001^*$	1.62
CV	24.61 ± 3.92	-1.334	.002*	1.32
CON	25.95 ± 4.07	-		

*indicates a significant difference compared with CON ($p < .05$).

Cognitive Performance (DSST)

A two-way repeated-measures ANOVA indicated no main effect of treatment on DSST completion time ($F(3,39) = 1.615$, $p = .202$, $\eta^2 = .110$) and no treatment $\times$ time interaction ($F(3,39) = 0.248$, $p = .862$, $\eta^2 = .019$). However, a significant main effect of time was observed ($F(1,13) = 25.535$, $p < .001$, $\eta^2 = .663$), indicating that DSST completion time was higher post-exercise than pre-exercise, across conditions. Descriptive data (mean $\pm$ SD) for DSST completion time are presented in Table II.

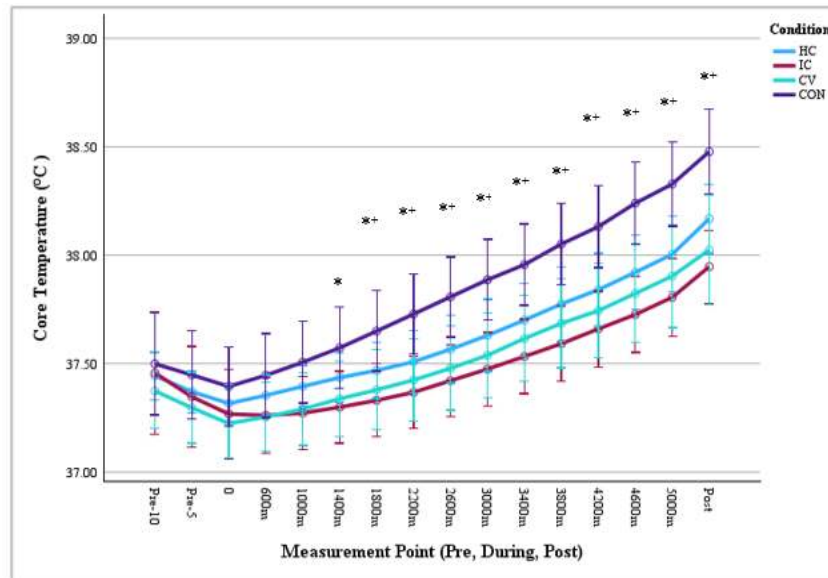
Table II. Cognitive performance (DSST)

Condition	Pre (s)	Post (s)
HC	83.50 ± 15.18	90.36 ± 12.36
IC	85.64 ± 13.77	92.93 ± 13.58
CV	84.93 ± 15.61	89.93 ± 13.40
CON	78.07 ± 17.85	84.07 ± 17.89

*Physiological Measure**Core Temperature (Tc)*

Descriptive data for core temperature across all time points are illustrated in Figure 1. Core temperature increased progressively over the 5-km time trial in all conditions, with higher end-exercise and early recovery values in CON compared with the cooling conditions. At the end of the time trial (5km/5000 m), mean Tc was $38.33 \pm 0.34^\circ\text{C}$ in CON compared with $38.00 \pm 0.30^\circ\text{C}$ (HC), $37.81 \pm 0.31^\circ\text{C}$ (IC), and $37.90 \pm 0.41^\circ\text{C}$ (CV). A similar pattern was evident at 2 min post-exercise: $38.48 \pm 0.34^\circ\text{C}$ in CON versus $38.17 \pm 0.28^\circ\text{C}$ (HC), $37.95 \pm 0.29^\circ\text{C}$ (IC), and $38.02 \pm 0.44^\circ\text{C}$ (VC).

Two-way repeated-measures ANOVA showed significant main effects of treatment ($F(3,39) = 4.238$, $p = .011$, $\eta^2 = .246$) and time ($F(15,195) = 203.859$, $p < .001$, $\eta^2 = .940$), as well as a significant treatment $\times$ time interaction ($F(45,585) = 4.022$, $p < .001$, $\eta^2 = .236$), indicating that the pattern of Tc change over the trial differed between conditions. Bonferroni-adjusted pairwise comparisons indicated that differences between conditions emerged primarily during the mid-to-late stages of exercise, with IC and CV generally exhibiting lower Tc than CON at several time points, whereas differences between the cooling conditions were not detected (all $p > .05$ at multiple early time points). Post-hoc analyses showed that IC elicited lower Tc than CON from 1800 m to post exercise (mean differences = -0.319 to -0.530°C , all $p \leq .006$), with large effect sizes ($d_z = 0.87$ - 1.31). Similarly, VC reduced Tc compared with CON from 2200 m to post exercise (mean differences = -0.304 to -0.453°C , all $p \leq .004$), also showing large effects ($d_z = 0.93$ - 1.25).



*indicates a significantly different IC compared with CON ($p < .05$). + indicates a significantly different CV compared with CON ($p < .05$).

Figure 1. Mean ($\pm$ SD) of core temperature across experimental trials.

Heart Rate (HR)

Heart rate responses across the 5-km time trial are presented in descriptive form in Figure 2. Repeated-measures ANOVA showed no main effect of treatment on heart rate ($F(2.01, 26.12) = 1.40$, $p = .265$, $\eta^2 = .097$), indicating that mean HR did not differ between HC, IC, CV, and CON when averaged across measurement points.

There was, however, a large main effect of time ($F(3.64, 47.36) = 395.56$, $p < .001$, $\eta^2 = .968$), reflecting the expected increase in heart rate from pre-exercise values to peak values during the time trial, followed by a reduction during recovery (post).

The treatment $\times$ time interaction was not significant ($F(4.75, 61.79) = 1.36$, $p = .255$, $\eta^2 = .094$), suggesting that the pattern of HR change over time was comparable across conditions.

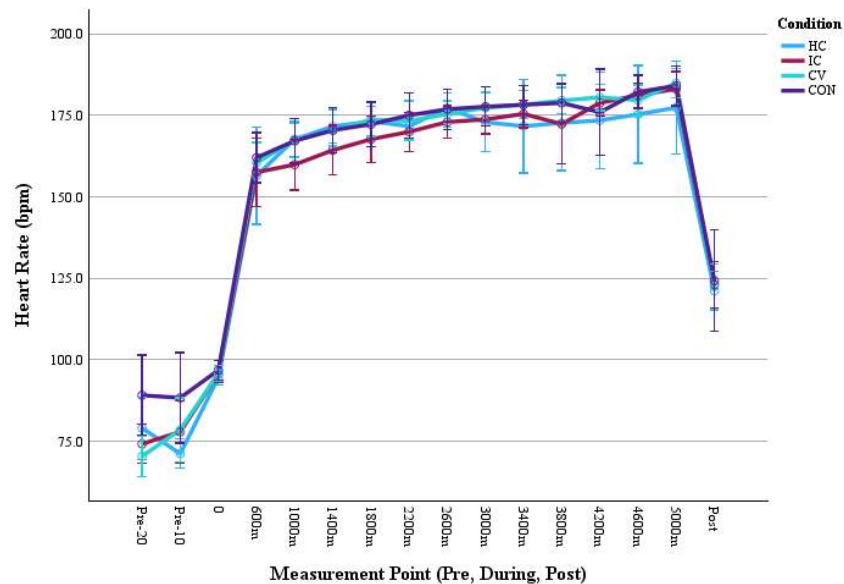


Figure 2. Mean ($\pm$ SD) of heart rate across experimental trials.

Perceptual Responses

Rating of Perceived Exertion (RPE)

RPE across the 5-km time trial are summarised descriptively in Figure 3. Repeated-measures ANOVA showed no significant main effect of treatment on RPE ($F(2.73, 35.48) = 1.98, p = .140, \eta^2 = .132$), indicating that average perceived exertion did not differ significantly between HC, IC, CV, and CON when averaged across measurement points. There was a significant main effect of time ($F(1.65, 21.48) = 48.57, p < .001, \eta^2 = .789$), reflecting the expected progressive rise in perceived exertion as the time trial progressed, followed by a reduction during recovery. The treatment x time interaction was not significant ($F(5.73, 74.47) = 0.27, p = .943, \eta^2 = .021$), suggesting that the progression of RPE development was comparable across all conditions.

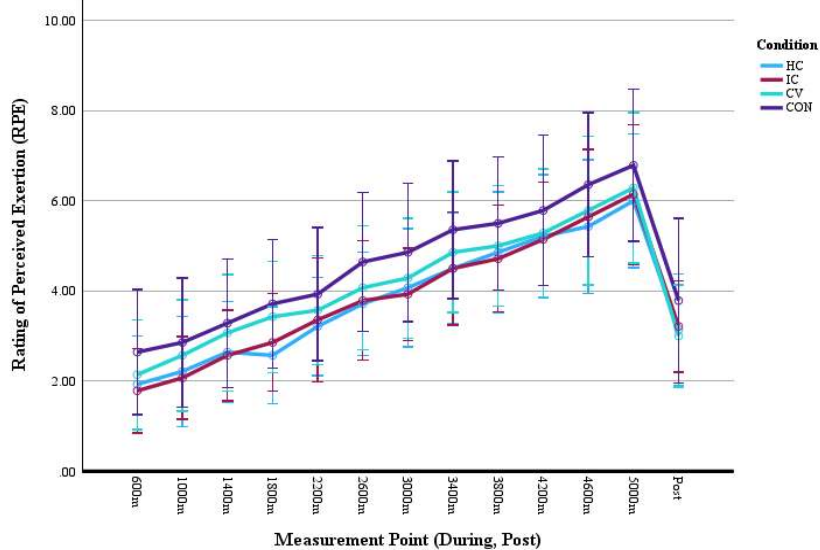


Figure 3. Mean ($\pm$ SD) of Rating Perceived Exertion (RPE) across experimental trials.

Thermal Sensation (TS)

TS responses across the 5-km time trial are presented descriptively in Figure 4. Repeated-measures ANOVA showed no significant main effect of treatment on TS ($F(2.48, 32.30) = 2.48, p = .089, \eta^2 = .160$), indicating that overall TS did not differ significantly between HC, IC, CV, and CON when averaged across measurement points. In contrast, there was a significant main effect of time ($F(2.82, 36.66) = 68.50, p < .001, \eta^2 = .840$), reflecting a progressive increase in perceived thermal strain as the time trial progressed. The treatment x time interaction was not significant ($F(7.14, 92.83) = 1.10, p = .368, \eta^2 = .078$), suggesting that the time-course of thermal sensation was comparable across all conditions.

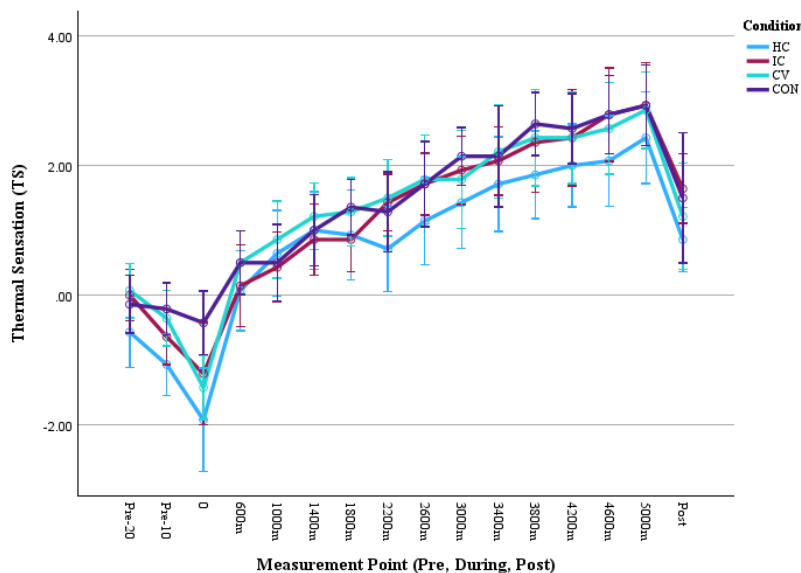


Figure 4. Mean ($\pm$ SD) of thermal sensation (TS) across experimental trials.

Discussion

The present study compared three field-practical cooling strategies, head cooling (HC), ice cooling (IC), and a cooling vest (CV) combined with standardised per-cooling ice ingestion on 5-km self-paced running performance in a hot, humid outdoor environment. The primary finding was that all cooling strategies produced a significant performance advantage over control (CON), with large within-subject effects (effect sizes) and better completion times (~1.3–1.8 min faster). This supports the larger body of research showing that pre-cooling and per-cooling may benefit endurance performance in hot conditions by reducing the rise in heat strain and increasing exercise tolerance to heat stress (Bongers et al., 2017; Cowe et al., 2025; Heydenreich et al., 2023; Periard et al., 2021; Yu et al., 2024). Notably, no differences in time-trial performance were found across HC, IC, and CV despite differing pre-cooling techniques. This suggests that, when applied in real-world settings, all strategies were equally successful at enhancing self-paced performance under the current methodology.

Self-paced performance in the heat

Self-paced endurance performance is often compromised in hot environments, as increasing core temperature and related cardiovascular and perceptual strain limit the potential work rate (Duffield et al., 2010; Kay et al., 1999; van de Kerkhof et al., 2024). In this study, all cooling interventions improved self-paced running performance compared with CON, but without a clear superiority of different cooling modalities. This outcome aligns with meta-analytic findings indicating that various cooling techniques can be beneficial, and that the magnitude of benefit often depends on underlying factors and contexts such as severity of environmental conditions, exercise duration, and timing of cooling, rather than the specific technique alone (Heydenreich et al., 2023; Yu et al., 2024). In practical sense, this supports a “fit-for-purpose” concept where athletes and practitioners may choose cooling strategies based on feasibility and preference, such as logistical simplicity of ice ingestion versus comfort and practicality of cooling vest or head cooling, as long as the purpose of cooling is achieved and effective.

A noteworthy practical aspect of the present cooling intervention is that per-cooling ice consumption was standardised throughout the cooling experiments. This may explain why the final performance outcomes were comparable among cooling strategies, as the internal per-cooling stimulus was maintained in the same way and magnitude across all cooling conditions. This aligns with the notion that the magnitude of pre-cooling stimulus may diminish over time during prolonged exercise (Douzi et al., 2020; Moss et al., 2021; van de Kerkhof et al., 2024). By applying the same per-cooling protocol, the physiological and perceptual outcomes of different pre-cooling modalities converged, suggesting that a sustained cooling stimulus is more influential in determining the end-point performance. Overall, these findings highlight the efficacy of combined pre-and per-cooling strategies in enhancing self-paced endurance performance by facilitating sustained effort over time.

Thermoregulatory responses

Core temperature (T_c) elevated progressively across all conditions, as anticipated during hot, humid outdoor running. However, core temperature did not reach the widely recognised critical threshold for performance impairment (~38.5–39.5°C) in any condition. The control condition (CON) almost reached this threshold, exhibiting a peak T_c $38.33 \pm 0.34^\circ\text{C}$ at the end of the trial. T_c was lower in IC and CV compared to CON during the mid-to-late stages of exercise and at early recovery, with a significant treatment $\times$ time interaction. This suggests that cooling reduced the development of thermoregulatory strain instead of fully preventing hyperthermia (Xue et al., 2018). The relatively decreased thermoregulatory strain during cooling conditions may have facilitated self-pacing and sustained exertion in the latter stages of exercise. This indicates that cooling may be most influential when cumulative heat load occurs to the levels that considerably interfere with pacing decisions (van de Kerkhof et al., 2024).

Notably, HC enhanced performance comparably to IC and CV, although having less significant evidence of T_c reduction in relation to CON. This emphasises a crucial finding from heat-performance models: cooling techniques can improve performance in several ways other than by reducing core temperature. These include perceptual and central mechanisms that improved heat comfort and reduced perceived heat stress (Cabanac, 1971; Hasegawa, 2014; Periard et al., 2021). In other words, performance gains are possible even when physiological indicators show only modest differences.

Cardiovascular and perceptual responses

Heart rate (HR), rating of perceived exertion (RPE), and thermal sensation (TS) demonstrated strong time effects, but no significant treatment effect or treatment $\times$ time interactions were observed. The results indicate that, although cooling resulted in better running performance, the overall increase of cardiovascular and perceptual strain progressed comparably across settings. In self-paced exercises, athletes frequently adjust their speed to maintain bearable internal strain, leading to comparable perceptual profiles despite variations in performance (Periard et al., 2021; van de Kerkhof et al., 2024). A possible explanation is that cooling allows runners to run faster at the same perceived effort and heat strain, which leads to improved performance without appreciably reducing RPE or TS. These findings suggest that some cooling benefits might be expressed as increased sustained output and not perceived effort reduction. Besides that, pacing strategies may control perceptual results when participants are told to finish the time trial as fast as possible, which could reduce TS and RPE differences between conditions even when performance improves.

Cognitive performance

Cognitive function, as measured by DSST completion time, had a significant main effect of time, indicating longer completion times post-exercise compared to pre-exercise across conditions, with no observed treatment effect or treatment x time interaction. This indicates that exercise and environmental heat stress have led to changes in cognitive performance, but the cooling stimulus may not have been sufficient to influence cognitive outcomes. However, the type of cognitive task, the timing of assessment in relation to exercise, and the degree of heat strain experienced throughout the exercise trial may all affect how well short cognitive tasks can identify cooling-related impacts (Donnan et al., 2021; Donnan et al., 2023; Mazalan et al., 2022a). In practical terms, physical performance and thermoregulatory modulation seem to be the main advantages of cooling strategies applied in this study, rather than measurable gains in DSST performance.

Practical implications

Despite being performance-oriented, these findings provide practical guidelines for exercising in hot, humid environments. Coaches and athletes can implement effective cooling strategies, such as ice consumption and a cooling vest to improve short-duration endurance performance. It is noteworthy that advantages may be obtained even in the absence of alterations in cardiovascular and perceptual responses. This study supports the use of portable, low-cost cooling strategies that are practical and adaptable to real-world settings.

Limitations and future directions

Several limitations should be considered. First, the sample size was modest and limited to moderately trained males, which restricts generalisability to other athletic populations. Second, although field-based designs improve ecological validity, outdoor conditions may lead to environmental variability in terms of solar radiation and wind conditions. Third, cognitive performance testing was limited to DSST completion time; future work should consider multi-domain cognitive batteries and include multiple measurement time points during exercise to better capture heat-related cognitive responses. Finally, because pre-cooling ice ingestion was standardised across cooling trials, future studies could also examine single modality testing to measure individual effectiveness.

Conclusions

This study demonstrates that practical cooling strategies can meaningfully improve 5-km self-paced running performance in hot and humid outdoor conditions. Head cooling, crushed ice ingestion, and cooling vest application, when combined with standardised pre-cooling ice ingestion, all produced faster completion times than the control condition. Importantly, no clear performance differences were observed among the cooling strategies, suggesting that several field-feasible approaches can be effective when the cooling method is practical, tolerable, and appropriately applied.

The main contribution of this study is that cooling benefits were observed under realistic outdoor conditions, where environmental heat, pacing decisions, and perceptual demands occur simultaneously. These findings support the theoretical view that cooling may enhance endurance performance by reducing thermoregulatory strain, limiting the rise in body temperature, and allowing athletes to sustain a higher self-selected pace. The results also indicate that improved performance can occur even when cardiovascular and perceptual indicators show limited differences between conditions, suggesting that the practical value of cooling may be reflected more clearly in performance output than in perceived effort alone.

From an applied perspective, crushed ice ingestion and cooling vest application appear particularly useful because they produced notable thermoregulatory benefits while remaining practical for sport settings. Coaches, athletes, and practitioners may consider integrating pre-cooling with simple pre-cooling strategies before and during endurance exercise in hot and humid environments. Such approaches may offer an efficient, low-cost, and adaptable method to reduce heat strain and support performance without substantially disrupting warm-up routines or competition preparation.

Overall, this study provides credible and applicable evidence that cooling interventions can serve as effective heat mitigation strategies for endurance exercise in hot outdoor conditions. The findings may contribute to the development of practical cooling protocols and encourage more individualised “fit-for-purpose” cooling practices based on athlete preference, event demands, and logistical feasibility. Future research should examine these strategies in larger and more diverse athletic populations, including female athletes and different performance levels, and should further investigate single-modality cooling effects and broader cognitive outcomes during exercise in the heat.

Conflicts of interest

The authors declare no conflicts of interest related to the content of this study.

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Authors' Contributions Author 1 was responsible for the experimental design, data collection, and manuscript drafting. Author 2 contributed to the study conception and data interpretation. Author 3 was responsible for data analysis and manuscript preparation. All authors read and approved the final manuscript.

Declaration of AI Use

During the preparation of this work, the author(s) used ChatGPT to assist with grammatical checking, rephrasing, and refining for language clarity. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

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