

Effect of wearing an ice cooling jacket on repeat sprint performance in warm/humid conditions

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Objective: To examine the effect of cooling the skin with an ice jacket before and between exercise bouts (to simulate quarter and half time breaks) on prolonged repeat sprint exercise performance in warm/humid conditions.

Methods: After an initial familiarisation session, seven trained male hockey players performed two testing sessions (seven days apart), comprising an 80 minute intermittent, repeat sprint cycling exercise protocol inside a climate chamber set at 30°C and 60% relative humidity. On one occasion a skin cooling procedure was implemented (in random counterbalanced order), with subjects wearing an ice cooling jacket both before (for five minutes) and in the recovery periods (2 × 5 min and 1 × 10 min) during the test. Measures of performance (work done and power output on each sprint), heart rates, blood lactate concentrations, core (rectal) and skin temperatures, sweat loss, perceived exertion, and ratings of thirst, thermal discomfort, and fatigue were obtained in both trials.

Results: In the cooling condition, chest (torso) skin temperature, thermal discomfort, and rating of thirst were all significantly lower ($p < 0.05$), but no significant difference ($p > 0.05$) was observed between conditions for measures of work done, power output, heart rate, blood lactate concentration, core or mean skin temperature, perceived exertion, sweat loss, or ratings of fatigue. However, high effect sizes indicated trends to lowered lactate concentrations, sweat loss, and mean skin temperatures in the cooling condition.

Conclusions: The intermittent use of an ice cooling jacket, both before and during a repeat sprint cycling protocol in warm/humid conditions, did not improve physical performance, although the perception of thermal load was reduced. Longer periods of cooling both before and during exercise (to lower mean skin temperature by a greater degree than observed here) may be necessary to produce such a change.

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It is well documented that heat strain, as a result of an elevated core body temperature, is a major cause of reduced exercise performance and heat related illnesses.^{1–4} Underlying all heat related illnesses is the inability of the body to rid itself of the excess heat produced.⁵ When team sports, which require repeated high intensity short sprints, are played in hot/humid conditions for 70–120 min (plus warm up and extra time), the possibility of players succumbing to some form of heat illness increases.⁶ However, by precooling the body, it may be possible to lessen the impact of hot and/or humid conditions on both exercise performance and athlete wellbeing.⁷ In particular, cooling between exercise bouts at quarter/half time breaks in games has not been evaluated, and it is at these times that cooling procedures may be of most practical use.

Precooling should lower skin temperature, but it may also result in small decreases in core temperature. Precooling can therefore delay the rise in both core and skin temperatures during exercise, increasing the time to the so called critical temperatures where performance may be affected.^{8–9} Along with a widening of this “margin of safety” there may also be a delay in the redirection of blood flow to the skin, which may theoretically allow a higher muscle blood flow,^{10–11} which, although not experimentally documented, may potentially provide a greater aerobic energy supply and/or a reduction in muscle and blood lactate concentrations.

To gain these potential physiological improvements, different methods of precooling have been attempted: immersion in cold water,¹² exposure to cold ambient temperatures in a climate chamber,⁸ and direct skin cooling with the use of water perfused suits and wet towels.^{10–13} Relatively recently, cooling jackets have come to prominence as a simple and efficient field method by which athletes can reduce skin temperature and attempt to counter the negative effects of heat strain.

Precooling methods have been shown to limit the effects of hyperthermia and produce improvements in exercise performance in all out, six minute rowing ergometer tests,¹⁰ in 2000 m rowing ergometer time trials,¹⁴ and in cycle and treadmill exercise of longer durations (30 minutes plus).^{15–16} However, precooling failed to elicit any exercise improvements in a step-wise cycle ergometer exercise test to exhaustion.⁸ Although research supports the ergogenic qualities of cooling body temperatures before continuous aerobic exercise in hot conditions, a recent report¹⁷ failed to find any significant improvement in exercise performance for an intermittent soccer specific exercise protocol performed in cool conditions, after a 60 minute precooling intervention. Although both core and skin temperature were significantly lowered before exercise, this did not translate into performance improvement, nor any differences in oxygen consumption, perceived exertion, heart rate, or substrate metabolism at the finish of the 90 minute intermittent running protocol when compared with a non-cooling condition. However, other authors¹⁰ have found improvements in mean power output for a maximal 70 second cycle ergometer test after whole body precooling. This result shows the potential of precooling for improving exercise performance in short duration, high intensity exercise, where the effects of thermoregulation on performance are less influential.

Thus far, no research has investigated the influence of cooling both before and between exercise bouts on intermittent repeat sprint exercise (as occurs in team sport games where there are established quarter/half time breaks). As team sports have only a small time frame between the cessation of the warm up and the start of game play, the opportunity for an initial precooling exposure before the start of play may only be of a short duration. Although some athletes have used the cooling jacket during warm up activities (possibly attenuating

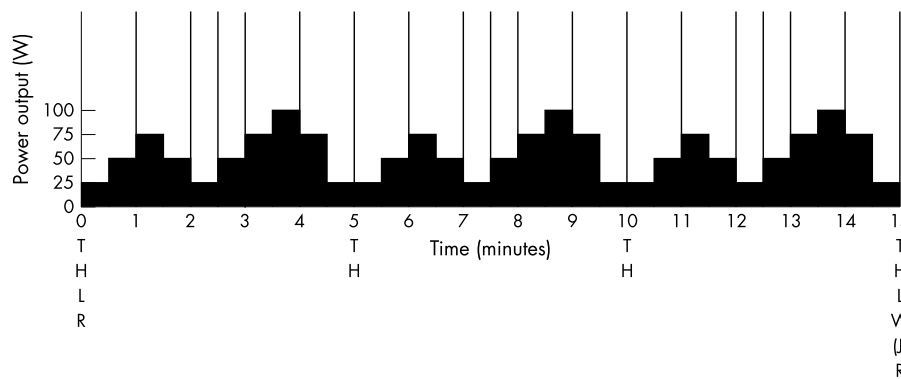


Figure 1 Intermittent exercise and testing protocol. Six second sprints are indicated by thin black lines, and recovery intensities by black shading. T, Temperature; H, heart rates; L, blood sample for lactate measurement; W, water; J, ice cooling jacket; rating scales.

the rise in skin temperature), in order to isolate the effects of a precooling procedure, a short non-exercise period was used here as a typical representation of the time between warm up cessation and the start of the game. Anecdotal reports have indicated that the ice cooling jackets have also been used in team sports—for example, field hockey, Australian football—during the designated game breaks. Therefore, whether such a short precooling application and/or additional cooling during game breaks is effective in improving exercise performance is yet to be determined. Accordingly, the objective of this study was to investigate whether cooling before and during high intensity exercise of an intermittent nature (consisting of multiple repeated short sprints with designated quarter and half time breaks) could improve exercise performance.

METHODS AND PROCEDURES

Sample

The seven male subjects used in this study were all first grade field hockey players (and therefore familiar with intermittent exercise activity) and were tested near the end of their competitive season. All gave their informed consent to participate in the study after approval for the procedures was granted by the University of Western Australia human ethics committee. Mean (SD) values for age, mass, height, sum of six skinfolds,¹⁸ and body surface area (Dubois nomogram) were as follows: 20.2 (2.2) years, 69.3 (6.7) kg, 179.1 (3.7) cm, 47.4 (15.7) mm, and 1.88 (0.09) m².

Procedure

Research design

Subjects were required to attend three testing sessions, each of which was separated by seven days. Initially, subjects engaged in a familiarisation session, followed by either the control condition (no ice cooling jacket) or the experimental condition (with the ice cooling jacket). The order of these last two sessions was randomised so as to avoid any order effect. In each session subjects performed an 80 minute intermittent sprint cycling exercise protocol wearing running shoes, t shirt, and shorts (standard hockey clothing). They were asked to refrain from any vigorous exercise for 24 hours before undertaking any of the testing sessions, and to avoid any food, drink, cigarettes, or caffeinated products during the two hours before the start of a testing session.

Exercise protocol

The exercise pattern was an intermittent repeated sprint cycling protocol for 80 minutes, consisting of four identical 15 minute quarters (mimicking the duration of a team sport game). Five minute rest periods were allowed between the first and second quarters and between the third and fourth quarters, with a 10 minute half time break. The protocol consisted of a five second sprint every minute, followed by 55 seconds of recovery at varying intensities (thus, each sprint

occurred on the minute). The rationale behind the exercise protocol was to attempt to simulate the type of intermittent, repeat sprint activity that occurs in many team sports. The continually changing nature of the recovery intensity level used in this protocol was an attempt to simulate the continual change in exercise intensity observed during intermittent activity—that is, walking to jogging to sprinting, back to jogging again, and so on. However, in an attempt to induce a greater degree of metabolic strain, three extra sprints at 2.5, 7.5, and 12.5 minutes were added. The work done and power produced on these extra sprints was not recorded. Figure 1 outlines the exercise and measurement protocol.

Experimental procedures

The control testing session began with weighing the subject to obtain their nude mass. Standardised prehydration then occurred with the ingestion of 500 ml water, during which the subject was made ready with all measuring devices. Subject preparation took place in an air conditioned environment of 20–25°C dry bulb temperature. A rectal probe was positioned 10 cm beyond the anal sphincter, and skin thermistors were placed on the sternum, chest (3 cm to the right of the left nipple), right forearm, right anterior quadriceps, and right posterior calf. A Polar heart rate transmitter and accompanying LSD receiver were attached. The subject then entered the climate chamber (already stable at the preset 30°C ambient temperature and 60% relative humidity, chosen to represent typical outdoor environmental conditions encountered in the Atlanta summer Olympics) and sat on the cycle ergometer. Seat height was measured and kept constant for each testing session. The subject was strapped to the bike with a waist strap to prevent standing up, and toe clips with heel straps were used to stabilise the feet in the pedals. Once prepared, the subject remained seated in the warm/humid climate for 15 minutes while instructions were given about the exercise protocol, measures to be taken, and the need for maximal effort on each sprint. After this period, resting measures of heart rate, core and skin temperatures, lactate concentration, and rating scales for perceived exertion, thermal comfort, thirst, and fatigue were taken. The subject then performed a five minute warm up, consisting of three minutes of cycling at 75 W, before increasing to 100 W for the final two minutes. Within the last two minutes there were two practice sprint starts of 3–4 seconds duration (at 3.5 and 4.5 minutes). At the end of the warm up, core and skin temperatures, heart rate, and rating scale measures were again obtained. After the warm up, a five minute recovery period, in which the subject stretched (remaining on the bike, but with feet freed) occurred. In the final minute of the stretching period, the subject was strapped back into the pedals, and body temperatures, heart rate, and rating scale measures were again taken. The subject then began the exercise protocol, as shown in fig 1, with all measures recorded at the appropriate

times, including work done (kJ) and power output (W) recorded on each sprint performed (except those occurring on the half minute—that is, 2.5, 7.5, and 12.5 minutes). Strong verbal encouragement was given to elicit maximal effort on each sprint. Environmental temperatures (dry, wet, and black bulb) were also measured and recorded every 20 minutes.

At the end of each quarter and just before the start of the next, skin and core temperatures, heart rate (before and after the sprint—that is, both the last and first sprints of the respective quarters), rating scales, and a blood sample from a finger tip for lactate measurements were taken. The subject was given a five minute break at the end of the first and third quarter during which they remained seated on the bike and were allowed to ingest 250 ml water. During a 10 minute break after the second quarter of the test, the subject was again allowed to ingest 250 ml water and to dismount the bike in order to move around (but remained within the climate chamber). After the fourth quarter the exercise test concluded, and, once final core and skin temperatures, heart rate, rating scales, and a blood sample had been obtained, the subject left the climate chamber to be reweighed. All leads were removed and all unevaporated sweat was removed with a towel before weighing. The subjects was then free to leave the laboratory.

The experimental and control sessions were identical, apart from the application of the ice cooling jacket during the rest periods. The jacket was used during the break for stretching after the warm up (five minutes) and during each break in the exercise protocol (2 × 5 and 1 × 10 minute breaks). The jacket was donned once temperatures, heart rates, and rating scale measures had been obtained—that is, 30–40 seconds into the rest period. It was then removed about 15–20 seconds before the exercise was started again. Apart from the use of the jacket, all measurements, procedures, and items of equipment used were kept standard across all testing sessions. The pockets on the ice cooling jacket were filled with cubed ice before the start of the test, and then the jackets were placed in an insulated cooler in the climate chamber. Additional ice was stored in a different cooler within the chamber so that extra ice could be added to the jacket at the half time break.

Measures and apparatus

Cooling was achieved with an ice cooling jacket (AIS, Canberra, Australia), constructed from material similar to that of a wetsuit and shaped in the form of a vest, with a zipper on the front, allowing easy application and removal. Multiple pockets allowed the placement and removal of cold substances (ice/ice packs) to cool the torso region. The cooling jacket was worn over the exercise attire. Exercise was performed on an Evolution Track Cycle (Adelaide, South Australia, Australia), with performance (power output and work done on each sprint) measured by CEDAA computer software developed at the Western Australian Institute of Sport. Heart rates were measured with a Polar Sports Tester (PE4000) (Kempele, Finland). Blood lactate concentrations were measured in microsamples of blood taken from a finger. They were determined with an Analox LM3 Multi Stat Analyser (Sheffield, Yorkshire, UK). Technical error of measurements (TEMs) ranged from 0.12 to 0.83 mmol/l for blood lactate concentrations in the range 1–10 mmol/l. Skin and rectal temperatures were recorded by either a Grant 1200 Series Squirrel Meter/Logger (Cambridge, UK) or a Yellow Springs Instruments model 46 TUC Telethermometer (Yellow Springs, Ohio, USA). Thermistor leads used were Grant EU-U2 Surface Probes (skin thermistors) and a Grant Rectal probe for the Squirrel (Cambridge, UK), with YSI model 408 skin thermistors and a YSI model 401 rectal probe for the Telethermometer. Mean skin temperatures were calculated using the method of Ramanathan¹⁹:

$$\text{Mean skin temperature} = (0.3 \times \text{sternum temperature}) + (0.3 \times \text{forearm temperature}) + (0.2 \times \text{quadriceps temperature}) + (0.2 \times \text{calf temperature}).$$

Sweat loss was estimated from the change in nude body mass during exercise accounting for any fluid ingested and urine voided. Relevant psychological states were assessed by rating scales consisting of a rating of perceived exertion (RPE) scale,²⁰ a 16 point bipolar scale for rating of thermal comfort (with anchors of 0.0 (unbearably cold) through to 8.0 (unbearably hot)), a 10 point bipolar scale for rating of thirst (with anchors of 0 (not thirsty) through to 10 (extremely thirsty)) (both of which were constructed similarly to the Borg scale), and a fatigue/vigour scale, which were subcomponents of the profile of mood states (POMS) checklist.²¹ All psychological variables were recorded in the two minutes before the start of exercise and again immediately after the completion of each quarter. A climate chamber located within the Western Australian Institute of Sport laboratory was used for the testing, with a radiant heat source (3000 W) being simulated by a heat lamp located 2.5 m to one side of the subject. Measures of the environmental conditions were regularly made by recording wet, dry, and black bulb temperatures using a Reuter Stokes RSS-212 Wibget heat stress monitor (Cambridge, Ontario, Canada).

Statistical analysis

Analysis of the means of the data over the four quarters for performance, core and skin temperatures, heart rates, and lactate concentrations were conducted using a two way (condition ν time) analysis of variance with repeated measures. Where appropriate, Scheffe post hoc comparisons were used. Overall performance measures and sweat losses were analysed using a dependent samples t test. Analysis of the rating scale measures (RPE, thermal comfort, thirst, and fatigue/vigour) was also carried out using a two way repeated measures analysis of variance. Statistical significance was set at $p < 0.05$. Effect sizes (Cohen's $d = (X_{\text{exp}} - X_{\text{con}}) / SD_{\text{con}}$)²² were also calculated for all measured variables. Effect size results were interpreted as described by Christensen and Christensen,²³ with effect sizes of < 0.2 classified as small, 0.4–0.6 as medium, and > 0.8 as large.

RESULTS

Exercise performance

Table 1 shows the mean total work done and power produced in each quarter and across the whole test. In addition, the mean work done per sprint in each quarter is also presented. Although five of the seven subjects performed more work and produced higher power levels in the cooling condition, there were no significant differences between the two conditions for work done or power output, either quarter by quarter or over the whole test ($p > 0.05$). In addition, there was no significant decline in work completed over time (no significant difference recorded between the first and last quarter work scores) ($p > 0.05$), nor for the mean work done per sprint in each quarter ($p > 0.05$). Overall, the effect sizes were small for all work and power variables ($d < 0.3$).

Temperatures

Table 2 gives the mean core, skin, and chest temperatures recorded throughout the test. No significant differences, as well as small effect sizes, were found between the mean core temperatures recorded throughout the exercise test in the two conditions ($p > 0.05$ and $d < 0.3$). The change in core temperature across the test (from the start of the test, including the warm up) was not significant between conditions (1.4°C no cooling ν 1.2°C cooling; $p > 0.05$), as was the change in core temperature between the end of the warm up and start of the test (−0.06°C no cooling ν −0.08°C cooling). However, there was a tendency for a slight reduction in the rise in core temperature in the cooling condition, with a lowered mean change in core temperature as the experiment continued ($p = 0.072$, $d = 0.7$).

Although a trend for lower mean skin temperatures in the cooling condition was noticeable (at the start of exercise and each quarter), no significant differences were found between

Table 1 Work done and power produced in each quarter and over the whole test for the cooling and non-cooling conditions, also including mean work done per sprint in each quarter

	Total mean work (kJ)		Mean work per sprint (kJ)		Mean power (W)	
	Cooling	Non-cooling	Cooling	Non-cooling	Cooling	Non-cooling
Quarter 1	59.4 (8.9)	59.5 (10.2)	3.7 (0.5)	3.7 (0.6)	937 (135)	933 (140)
Quarter 2	60.0 (8.1)	57.5 (11.3)	3.7 (0.5)	3.6 (0.7)	939 (126)	903 (173)
Quarter 3	58.4 (7.7)	56.8 (10.5)	3.6 (0.5)	3.6 (0.7)	912 (118)	888 (152)
Quarter 4	58.7 (7.7)	56.3 (10.6)	3.6 (0.5)	3.5 (0.6)	899 (164)	899 (164)
Test total	239.8 (33.9)	230.2 (41.9)	–	–	928 (123)	906 (155)

Values are mean (SD).

Note: no significant differences were recorded between conditions.

Table 2 Core, skin, and chest temperature at the start and finish of each quarter (Q) (°C) for the cooling (Cool) and non-cooling (Non cool) conditions

	Q1		Q2		Q3		Q4	
	Start	Finish	Start	Finish	Start	Finish	Start	Finish
Core								
Cool	37.4 (0.3)	38.0 (0.3)	38.2 (0.3)	38.5 (0.3)	38.4 (0.3)	38.5 (0.3)	38.6 (0.3)	38.7 (0.3)
Non cool	37.5 (0.3)	38.1 (0.3)	38.2 (0.3)	38.6 (0.3)	38.5 (0.3)	38.6 (0.4)	38.6 (0.3)	38.8 (0.3)
Mean skin								
Cool	34.2 (0.7)	34.3 (0.4)	34.9 (0.6)	34.1 (0.6)	34.2 (0.7)	33.6 (0.8)	34.4 (0.5)	33.6 (0.6)
Non cool	34.5 (0.6)	34.5 (0.7)	35.2 (0.8)	34.2 (0.6)	34.9 (0.3)†	33.9 (0.7)	35.0 (0.9)†	34.0 (0.7)
Chest								
Cool	30.1 (1.2)	33.2 (1.5)	28.9 (3.3)	33.5 (1.4)	26.0 (4.3)	32.6 (1.9)	25.5 (4.6)	32.8 (1.8)
Non cool	34.5 (0.6)*	34.2 (1.2)	35.3 (1.2)*	34.1 (1.0)	35.4 (0.7)*	33.9 (1.1)	35.4 (1.1)*	33.7 (1.2)

Values are mean (SD).

*Significant difference between conditions ($p < 0.05$).

†Large effect size between conditions ($d \geq 0.8$).

Table 3 Blood lactate concentrations recorded at the start and end of each quarter for cooling (Cool) and non-cooling (Non-cool) conditions

	Q1		Q2		Q3		Q4	
	Before	After	Before	After	Before	After	Before	After
Cool	1.6 (0.5)	5.3 (1.6)*	4.3 (1.0)	5.2 (1.5)*	3.6 (0.9)	4.2 (0.8)*	3.5 (0.4)*	4.4 (0.7)*
Non-cool	1.8 (0.4)	6.2 (0.7)	4.9 (1.0)	5.8 (0.8)	3.7 (0.7)	5.0 (0.5)	4.3 (0.3)	5.1 (0.9)

Values are mean (SD).

Note: There were no significant differences between conditions ($p > 0.05$).

*Large effect size between conditions ($d \geq 0.8$).

the two conditions for either mean skin temperatures or the change in mean skin temperatures across time, including mean skin temperature at the start of the test—that is, after the warm up (34.2 (0.7) cooling, 34.5 (0.6) no cooling) ($p > 0.05$). However, very large effect sizes were found for mean skin temperature after half time ($d = 2.3$) and for the change in each period after quarter time ($0.7 < d < 1.4$), with reduced temperatures being noted in the cooling condition (table 2). In addition, a significant difference ($p < 0.02$) was found for the mean chest temperature—that is, under the ice cooling jacket. Post hoc comparisons showed that at the start of each quarter there was a significant difference ($p < 0.05$) between the conditions for mean chest temperature, with temperatures in the cooling condition not reaching control levels until the very end of the quarter ($d > 4.0$ at the start of each quarter).

Heart rate

There were no differences observed between the cooling and non-cooling conditions for heart rates before or after the sprint ($p > 0.05$), which ranged from an average of 145 to 157 beats/min for each of the quarters.

Lactate concentration

Although no significant difference in the means of the two conditions was observed ($p > 0.05$), slightly lower blood lactate concentrations were recorded in the cooling condition at the end of each quarter and at the start of the next quarter (table 3). Starting concentrations were similar (1.8 mmol/l for the non-cooling condition compared with 1.6 mmol/l for the cooling condition), but at the end of the exercise protocol lactate concentrations were 5.1 mmol/l (non-cooling) and 4.3 mmol/l (cooling) respectively. Large effect sizes at the start and end of each quarter were found, with lactate concentrations being lower in the cooling condition ($0.7 < d < 2.6$) (apart from after the 10 minute half time break).

Change in body mass

Mean decrease in body mass across the test for the non-cooling condition was 2.10 (0.51) kg whereas in the cooling condition it was 1.70 (0.30) kg. Although not significant ($p > 0.05$), a large effect size ($d = 0.8$) was noted.

RPE

Mean (SD) RPE in the non-cooling condition was 11.9 (3.6) and 11.0 (3.2) in the cooling condition ($p > 0.05$). Likewise, no

differences for the final rating (17.1 (2.0) for non-cooling and 15.0 (3.0) for cooling) at the end of exercise was noted ($p > 0.05$; $d = 1.05$). However, after the half time break, moderate to strong effect sizes ($d = 0.7$ – 1.2) were found for lower RPEs in the cooling condition.

Thermal comfort

Mean (SD) thermal comfort over the whole test for the non-cooling condition was 5.9 (0.7) compared with 5.0 (1.3) for the cooling condition ($p > 0.05$). However, significant differences ($p < 0.05$) between the cooling condition and the non-cooling condition were found at 0, 20, 45, and 60 minutes: 2.9 (1.2) v 5.2 (0.6), 3.8 (0.1) v 5.4 (0.7), 3.8 (1.1) v 5.6 (0.5) and 4.0 (1.2) v 5.9 (0.6).

Ratings of thirst

Significant differences ($p < 0.05$) were found between the conditions over time, with the mean (SD) rating of thirst over the whole test in the non-cooling condition being 3.1 (2.1) and in the cooling condition 2.9 (1.3).

Fatigue and vigour scale

No significant differences ($p > 0.05$) were found between the non-cooling and cooling conditions for either the fatigue scale (fatigued, exhausted, weary, worn out, bushed) or the vigour scale (vigorous, energetic, lively, active, full of pep), with no trends evident. However, in both conditions subjects reported increased feelings of fatigue (on all fatigue scales) over time ($p < 0.05$), and lowered ratings on the energetic, active, and full of pep scales over the duration of the exercise protocol ($p < 0.05$).

DISCUSSION

The aim of this study was to investigate whether the use of an ice cooling jacket for brief periods before and during intermittent, repeated sprint exercise of a team sport type duration could improve exercise performance. The use of cooling procedures in designated "breaks" during prolonged exercise tests has not been previously examined. The results indicated that no significant differences existed between the cooling and non-cooling conditions in measures of cycling sprint performance, core and mean skin temperature, blood lactate concentration, heart rate, change in body mass, RPE, or fatigue/vigour scale ratings. Because of small subject numbers, effect size analysis was used to indicate whether trends noted in the data were small, moderate, or large. Effect sizes were moderate to large for lower lactate concentrations, sweat loss, and mean skin temperatures in the cooling trial. Significantly lower values ($p < 0.05$) were found for the cooling condition for measures of chest (torso) temperature, rating of thermal comfort, and rating of thirst.

Significant improvements in continuous, submaximal, and maximal aerobic exercise performance (6–35 minutes)^{14, 15} after 10–15 minutes of precooling with ice jackets have been reported. In contrast, Drust *et al*¹⁷ did not find any improvement in distance covered over a 90 minute intermittent non-motorised treadmill running protocol (after a 60 minute cold shower, with a 15 minute break before the start). However, in their study, subjects ran at set speeds (in normothermic conditions) for most of the test protocol, thus not permitting any large degree of differentiation in distance covered (as a performance measure) between cooled and non-cooled conditions. Although our study did provide for a greater amount of maximal sprinting throughout the exercise protocol, the results again did not show any significant differences between the conditions for work done or power produced either after the initial cooling or with the additional cooling at the designated breaks (although five of the seven subjects did improve their exercise performance).

The absence of a notable reduction in core temperature after warm up may explain why the use of ice cooling jackets did not alter performance in this study. The three following studies all reported improved performance after precooling and all showed a significant reduction in core temperature. Yates *et al*¹⁴ used an ice cooling jacket for 10 minutes, which produced a small reduction (-0.5°C) in rectal temperature after the warm up, before a 2000 m rowing ergometer test. Similarly, Myler *et al*¹¹ used an eight minute precooling period (ice water towels) before the start of the same test, which was sufficient to produce a significant lowering of core (tympanic) temperature by 0.9°C . More recently, Marsh and Sleivert¹⁰ reported that rectal temperature was lowered by 0.3°C by cold water immersion (for 30 minutes) before a 70 second maximal cycle ergometer sprint. Therefore, a significant decrease in core temperature may be necessary for precooling to improve exercise performance.

As core temperature is strictly regulated,²⁴ it is likely that the cooling intervals used here of five minutes (and to a lesser extent, the 10 minute half time break) were not of sufficient duration to elicit any significant change in this variable. However, a short cooling duration before exercise (five minutes) was chosen for use here to simulate a more realistic game specific situation, where little time exists between the end of the warm up and the start of the game. Laboratory precooling methods of the sort and duration used by Schmidt and Bruck⁸ or Marsh and Sleivert,¹⁰ although successful at reducing core temperature, are not practical for a field competition setting. Moderate to large effect sizes ($d = 0.5$ – 1.0) recorded here did indicate a trend for a reduction in the rise in core temperature when the ice jacket was worn before exercise (and also during the half time break). Therefore, it is likely that a greater length of initial cooling may have allowed a significant reduction in core temperature before starting the test, and therefore a greater likelihood of performance enhancement. Although it is noted that the environmental and exercise load used here did not increase mean core temperature to greater than 39°C , the impact of precooling may have been increased with a greater hyperthermic load. However, an exercise protocol involving alternating intermittent work and recovery periods (as used here to simulate team sport activity) will limit the rise in core temperature, which might otherwise be achieved with a continuous exercise protocol. Also, cooling of the head and neck regions may assist in improving the impact of precooling, as the head is an area of great heat loss because of a lack of vasoconstriction in the cranial area.²⁵

Although mean skin temperature also showed no significant difference between conditions, examination of the effect size data again showed moderate effects of cooling after the pretest and third quarter break and large effects after the half time application of the cooling jacket. Large effect sizes ($d > 0.7$) were found for both a smaller change in mean skin temperature across quarters after the half time break and for a lowered mean skin temperature at the start of each quarter in the cooling condition. However, three of the four sites used in the calculation of mean skin temperature were not in the vicinity of the ice cooling jacket (which only covers the torso region). The use of the ice cooling jacket significantly reduced chest skin temperature (under the jacket while worn), with temperatures not reaching those displayed in the non-cooling condition until the end of the quarter (by which time the jacket was reapplied). Smith *et al*¹⁵ found skin temperatures under the ice cooling jacket during the warm up to be 10°C , compared with 33°C without the jacket. They hypothesised that the increased time measured until the onset of fatigue may have been a result of a decreased skin blood flow (thereby allowing an increased muscle blood flow), because of the cold temperatures produced on the torso skin. A greater amount of heat could then potentially be lost per unit of blood flow to the skin, helping to preserve central blood volume.¹⁷ Achieving a decrease in core temperature, in combination with a large reduction in skin temperature by precooling, may provide an

increased possibility of improving exercise performance after such procedures. However, it is important that the working muscles are not cooled by these procedures, as performance will be reduced if this is the case.²⁶

It is difficult to compare the results of the change in mean skin temperature found here with other studies, as cooling strategies have varied widely. Studies such as that of Olschewski and Bruck,²⁷ in which whole body ambient air cooling was used (duration of 30 minutes), obtained greater decreases in mean skin temperature (4°C difference between conditions) than studies such as the present one, where only the torso region was cooled (for only brief periods, while within warm/humid conditions).

After precooling, reduced heart rates have been reported during the early stages of prolonged exercise tests^{8, 16} and significant reductions in sweat loss,^{8, 26} but no difference in blood lactate concentrations.⁷ We failed to find any significant differences between conditions in heart rates, blood lactate concentrations, or changes in body mass as a result of sweat loss. However, although much discussion has focused on the physiological effects of precooling, the role of psychological influences cannot be discounted. Although difficult to quantify, it is possible that lowered feelings of heat strain could improve the comfort level of the athlete, which may in turn translate into reduced feelings of fatigue and a smaller decline in performance. At worst, the ice cooling jacket used here provided some relief from the heat, which, regardless of the influence on performance, is still valuable in hot/humid conditions, especially for people in an initial encounter or without prior exposure/acclimation to these types of conditions. Although cooling before and during exercise may relieve the feelings of thermal discomfort and thirst and provide a general perception that the exercise load is easier, because of the continual engagement in maximum effort sprints, it is unlikely that cooling will reduce RPE in repeated maximal sprint exercise. Correspondingly, other studies incorporating maximal exercise efforts have reported no changes to RPE with the administration of precooling,^{14, 15, 17} as, when exercise is maximal in intensity, RPE will reach a limit that should be the same for both conditions. The results here also showed no difference in the perception of fatigue or increased vigour reported by the subjects after the use of the ice cooling jacket. However, effect size data ($d = 0.7-1.0$) suggested large differences between conditions on both sets of scales after the application of the cooling jacket at half time, indicating that the lengthened half time exposure to a cold microclimate may have helped suppress feelings of fatigue and exertion during the second half.

In conclusion, the use of an ice cooling jacket for a short initial precooling exposure and for additional cooling during breaks throughout the intermittent exercise protocol did not improve exercise performance. Therefore, although it appears likely that the initial precooling exposure (five minutes) was not of sufficient duration to enhance exercise performance, there was some evidence of improved subject comfort in the cooling trial. Further trials of cooling both before and during prolonged intermittent exercise protocols that simulate the duration and intensity of typical team sports should be conducted, with longer exposure periods than used here, although applicability to the field competition setting must be considered. The use of ice jackets with hoods or the application of ice towels to the head should also be included to assist with greater body cooling.

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Take home message

Although the use of an ice cooling jacket reduced the perception of thermal load, it did not improve exercise performance in prolonged intermittent repeated sprint cycling efforts in warm/humid conditions.

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