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Research article

Effect of Pre-cooling on Repeat-Sprint Performance in Seasonally Acclimatised Males during an Outdoor Simulated Team-Sport Protocol in Warm Conditions

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Abstract
Whether precooling is beneficial for exercise performance in warm climates when heat acclimatised is unclear. The purpose of this study was to determine the effect of precooling on repeat-sprint performance during a simulated team-sport circuit performed outdoors in warm, dry field conditions in seasonally acclimatised males (n = 10). They performed two trials, one with precooling (PC; ice slushy and cooling jacket) and another without (CONT). Trials began with a 30-min baseline/cooling period followed by an 80 min repeat-sprint protocol, comprising 4 x 20-min quarters, with 2 x 5-min quarter breaks and a 10-min half-time recovery/cooling period. A clear and substantial (negative; PC slower) effect was recorded for first quarter circuit time. Clear and trivial effects were recorded for overall circuit time, third and fourth quarter sprint times and fourth quarter best sprint time, otherwise unclear and trivial effects were recorded for remaining performance variables. Core temperature was moderately lower (Cohen's *d*=0.67; 90% CL=-1.27, 0.23) in PC at the end of the precooling period and quarter 1. No differences were found for mean skin temperature, heart rate, thermal sensation, or rating of perceived exertion, however, moderate Cohen's *d* effect sizes suggested a greater sweat loss in PC compared with CONT. In conclusion, repeat-sprint performance was neither clearly nor substantially improved in seasonally acclimatised players by using a combination of internal and external cooling methods prior to and during exercise performed in the field in warm, dry conditions. Of practical importance, precooling appears unnecessary for repeat-sprint performance if athletes are seasonally acclimatised or artificially acclimated to heat, as it provides no additional benefit.

Key words: Cooling jacket, ice slushy, core temperature, 20 m sprint.

Introduction

Strenuous exercise (both intermittent and continuous) in heat can result in the attainment of a critically high core temperature (T_C), which is commonly in the range of 39.4 – 40.0ºC (Gonzalez-Alonso et al., 1999; MacDougall et al., 1974; Nielsen et al., 1993). Reaching a "critically high T_C" has been proposed by many researchers as an important factor in the premature (voluntary) termination of exercise and can often occur regardless of external conditions (Galloway and Maughan, 1997; Gonzalez-Alonso et al., 1999; MacDougall et al., 1974; Nielsen et al., 1993). Numerous studies comparing exercise performance in warm-hot (30-40°C) and thermoneutral (16-23°C) environments have reported impaired exercise performance (reduced time to exhaustion and total distance completed and mean power output) in warm-hot conditions in both endurance (Galloway and Maughan, 1997; MacDougall et al., 1974) and prolonged repeat-sprint exercise (Drust et al., 2005; Morris et al., 1998; Morris et al., 2000; Morris et al., 2005) tasks. Further, intermittent exercise is often associated with greater thermal loads, compared with endurance exercise of a matched intensity (Kraning and Gonzalez, 1991; Nevill et al., 1995).

An acute method proposed to improve exercise performance in heat is precooling. The rationale behind precooling is to delay the rise in T_C to a critical level, where exercise intensity cannot be maintained (Marino, 2002; Quod et al., 2006; Wendt et al., 2007). Precooling may aid exercise performance by increasing heat storage capacity and delaying the activation of heat dissipating mechanisms (Booth et al., 1997; Kay et al., 1999; Marino, 2002; Quod et al., 2006), as well as by inducing perceptual alterations that can cause a change in pacing strategies so to better cope with the metabolic, thermoregulatory and neuromuscular loads (Duffield and Marino, 2007; Minett et al., 2011).

To date, results from laboratory based studies examining the effect of precooling on repeat-sprint cycling performance in heat have been equivocal. Castle et al. (2006) reported a 4% improved peak power output in heat (~34°C and 52% relative humidity; RH) after precooling (ice packs on upper legs) compared with no precooling, whereas Duffield et al. (2003) found no significant benefit of using an ice jacket prior to and during exercise in 30°C and 60% RH. Other studies have examined the effects of combined precooling methods compared with singular methods, including ice vest vs ice bath and vest (32°C and 30% RH; Duffield and Marino, 2007); head vs head and hand vs a mixed-method including head, neck, hand, cooling jacket and ice packs on thighs (33°C and 34% RH; Minett et al., 2011); ice slushy and cooling jacket alone vs ice slushy and cooling jacket combined (35°C and 58% RH; Brade et al., 2012). Notably, Brade et al. (2012) reported improved repeated sprint performance, while Duffield and Marino (2007) and Minett et al. (2011) only reported improved sub-maximal exercise performance in heat following combined precooling techniques.

Another well established technique used to counteract the negative effects of heat on exercise performance is heat acclimatisation/acclimation (Marino, 2002). To date, numerous studies have reported improved exercise performance in heat when participants were heat acclimated (Nielsen et al., 1993; 1997; Sunderland et al., 2008). Two recent studies reported that heat acclimation alone resulted in improved repeat-sprint cycle performance in heat when compared with various precooling

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methods (ice packs on thighs: Castle et al., 2011; ice slushy and cooling jacket combined: Brade et al., 2013). As precooling is proposed to only be of benefit to exercise performance when heat strain is high (Duffield and Marino, 2007), both Castle et al. (2011) and Brade et al. (2013) suggested that the acclimation process resulted in physiological adaptations to heat that reduced heat strain in participants, thus rendering precooling ineffective.

Importantly, both studies by Castle et al. (2011) and Brade et al. (2013) were performed in controlled laboratory conditions using a repeat-sprint cycle (weight assisted) protocol. Possibly, if exercise consisted of repeated running sprints performed in the field during summer (with direct solar radiation), higher levels of heat strain might be produced, raising the potential for precooling to have a beneficial effect on exercise performance, despite heat acclimatisation or acclimation being in place. To date, no studies have assessed the effects of combined internal and external precooling methods, on sport specific repeat-sprint efforts performed by heat acclimated or acclimatised athletes. Therefore, the purpose of this study was to assess the effect of precooling (ice slushy and ice jacket combined) on repeat-sprint running performance in seasonally acclimatised team-sport athletes in a field setting in warm outdoor conditions.

Methods

Participants

Ten physically active males (mean ± SD: age 22 ± 3 y, height 1.79 ± 0.04 m, body mass 73.3 ± 5.1 kg, sum of seven skin-folds 53.6 ± 12.6 mm and body surface area 1.9 ± 0.1 m^2) were recruited as participants. All provided informed consent and ethical approval was granted by the Human Research Ethics Committee of the University of Western Australia. Testing was conducted during the latter summer months (where monthly average maximum temperatures were; 30.5°C, December; 33.5°C, January; 31.1°C, February; 31.4°C, March) so that participants were naturally heat acclimatised prior to participation in the study.

Overview

Following a familiarisation session (completed 5-7 days prior), participants completed two experimental trials (randomised, crossover design) performed at least 5 days apart and at the same time of day (± 2 h). The experimental sessions included a control (no cooling) trial (CONT) and a precooling (PC) trial that involved the simultaneous use of an ice slushy and cooling jacket. Both trials included a 30-min baseline/precooling period followed by 4 x 20-min quarters of repeat-sprint exercise separated by 2 x 5-min quarter breaks and a 10-min half-time recovery/cooling period. Participants replicated food and fluid intake for 24 h prior to each session, and abstained from alcohol and vigorous activity for 24 h and caffeine for 3 h prior to testing.

Procedures

Familiarisation session: Anthropometric measures including height (cm), body-mass (BM; kg), sum of seven skin-folds (Harpenden callipers; mm; triceps, biceps, subscapular, abdominal, suprailiac, thigh and calf), body surface area (m^2; Dubois nomogram; McArdle et al., 2001) were recorded. In addition, participants then performed one half of the exercise protocol in similar environmental conditions to the testing sessions to ensure familiarisation to the testing regime.

Cooling intervention: Trials began with a 30-min baseline period completed under normal laboratory conditions (21.9 ± 0.9°C; 55.3 ± 6.6% RH) whilst seated. During the PC trial, participants precooled during this time by simultaneously ingesting 7 $g{\cdot}kg^{-1}$ BM (Ihsan et al., 2010) of plain ice (0.6°C) and by wearing a cooling jacket containing PC25 (PCP Australia, West Perth, WA, Australia). To ensure consistency across trials, the ice slushy was consumed at a rate of 2.3 $g{\cdot}kg^{-1}$ BM every 10 min. When frozen, PC25 appears as a white, crystalline solid substance that has a melting point of 25°C and the ability to transfer 3.5 Watts (W) of heat per square cm from the body (manufacturer's details). The jacket, (Australian Institute of Sport, Canberra, ACT, Australia), is a vest with four anterior and posterior pockets into which sealed packets (140 mm x 140 mm, 120 g) of frozen PC25 were fitted. During the half-time recovery period, these precooling methods were used again in the PC trial for ~8-min. The amount of ice ingested was 2.3 $g{\cdot}kg^{-1}$ BM and the jacket was retrieved from the refrigerator where it was stored during the first half of the exercise protocol. To control for fluid intake between trials, participants in the CONT trial consumed identical amounts of tap water (~23°C) to ice consumed during the PC trial in both the baseline and half-time periods.

Exercise protocol: Following precooling, participants went to the outdoor exercise laboratory, where mean ± SD environmental conditions on test days for PC and CONT respectively were; dry bulb temperature 27.4 ± 3.5; 23.5 ± 8.5°C (Cohen's d=0.46; 90% CL=0.10, 1.21); black bulb 39.0 ± 8.6; 37.1 ± 9.4°C (Cohen's d=0.20; 90% CL=-0.45, 0.84); wet bulb 22.2 ± 2.6; 19.7 ± 3.1°C (Cohen's d=0.81; 90% CL=0.14, 1.48); RH 38.6 ± 12.6; 37.0 ± 10.7% (Cohen's d=0.15; 90% CL=-0.52, 0.77) and wind speed 4.1 ± 2.23; 4.0 ± 1.72 $m{\cdot}s^{-1}$ (Cohen's d=0.06; 90% CL=-1.30, 1.38). The wet bulb globe temperature index was ~25°C. To account for the (uncontrolled) outdoor environmental conditions and circadian variability, on every test day both PC and CONT trials were held at the same time of the day. Participants completed a 10-min warm-up which replicated that typically undertaken prior to a team-sport game and included light jogging, run throughs and stretching. The 80 min exercise circuit used (Bishop et al., 2001; Duvnjak-Zaknich et al., 2011) was designed to replicate the typical intermittent exercise demands and movement patterns observed in team-sports. Each 20-min quarter consisted of 20 x 1 lap repetitions, with a lap beginning each minute. Each lap involved three maximal sprints (2 x 10 m, 1 x 20 m), a 12 m agility (change of direction) section, one 30 m striding effort, two periods of jogging and three periods of walking. The total distance per lap repetition was ~122 m, equating to a total distance of

9760 m over the 80 min period (80 laps). The time taken to complete each lap was ~ 44-45 s. The first and third 20-min quarters were separated by a 5-min break, with a 10-min recovery/cooling period at half-time. Every 10 min of each quarter, 100 ml of water was ingested, as well as 50 ml each of water and a commercial sports drink (Powerade: 8% carbohydrate) during the 1st and 3rd quarter breaks, with 100 ml of the sports drink taken during half-time.

Measures

Nude BM was measured prior to baseline and then after exercise (towel dried) using a digital platform scale (model ED3300; Sauter Multi-Range, Ebingen, West Germany ± 10 g) for the purpose of calculating sweat loss (pre - post nude BM + fluid ingested). Heart rate (HR) values (Polar F1TM HR monitor, Kempele, Finland) were recorded at 0, 10 and 20 min of every quarter. Core temperature was also measured at these time points by an ingestible radiotelemetry capsule (VitalSense, Mini Mitter, OR, USA) swallowed 8 h prior to testing. Skin temperature (T_{Sk}) was measured at the beginning and end of every quarter by dermal patches (VitalSense, Mini Mitter, OR, USA) placed on the sternal notch, mid-forearm, mid-quadriceps and medial calf. Mean T_{Sk} [= (0.3 x sternum temperature) + (0.3 x forearm temperature) + (0.2 x quadriceps temperature) + (0.2 x calf temperature)] was calculated using the method described by Ramanathan (1964). Heart rate, T_C and T_{Sk} were also taken at the beginning and end of the baseline period. Ratings of perceived exertion (RPE; Borg, 1970; 6-20 scale) and thermal sensation (TS; 0 = unbearably cold to 8 = unbearably hot) were measured at the beginning and end of every quarter of exercise. Sprint times (20 m: 0.001 s) were recorded by electronic timing gates (Fitness Technology Inc., Skye, SA, Australia) for sprints 5, 10 and 20 of each quarter, whilst circuit times were recorded for every lap using a digital stopwatch (Hart Sport, Virginia BC, QLD, Australia; 0.01 s). Previous work from our laboratory has established the CV for mean (quarter) sprint time as 3.7% (90% CL=2.7, 6.0) and for best sprint time as 2.0% (90% CL=1.4, 3.1) within this circuit (Singh et al., 2010).

Statistical analyses

Given the likely small changes in 20 m sprint and lap times, the data was analysed using Cohen's *d* effect sizes (trivial 0.0 to <0.2; small 0.2 to <0.6; moderate 0.6 to <1.2; large 1.2 to <2.0) to identify the magnitude of difference between conditions for sprint and trial scores (Cohen, 1988). Smallest worthwhile changes were also calculated for sprint times (Batterham and Hopkins, 2006), with the smallest worthwhile change value over a 20 m sprint being calculated as a Cohen's unit of 0.2. Magnitude based inferences were used to assess effects between trials using the following qualitative probabilities: < 1%, almost certainly not; <5%, very unlikely; <25%, unlikely/probably not; 25-75%, possibly/possibly not; >75%, likely/probably; >95%, very likely; >99%, almost certainly (Hopkins, Marshall, Batterham & Hanin, 2009). Where the chance of benefit or harm were both calculated to be > 5%, the true effect was deemed unclear. All values are expressed as mean ± SD, whilst ES values are followed by 90% CL.

Results

A clear and substantial (negative; PC slower) effect was recorded for first quarter circuit time. Clear and trivial effects were recorded for overall circuit time, third and fourth quarter sprint times and fourth quarter best sprint time, otherwise unclear and trivial effects were recorded for remaining performance variables (Table 1).

Core temperature was moderately lower (Cohen's *d* = 0.67; 90% CL = -1.27, 0.23) in PC compared with CONT at the end of the precooling period (min 30; Table 2). Moderate Cohen's d effect sizes (Cohen's *d* = 0.67;

Table 1. Mean (± SD) 20 m sprint and circuit times overall and for each quarter, plus first and best sprint times of each quarter for the precooling (PC) and control (CONT) trials.

		Trial		Cohen's *d* Effect Size / Mean change (%) / 90 % confidence limits / Percentage chance that effect is beneficial (trivial/harmful) #
		PC	CONT	PC vs. CONT
Overall Sprint Time (s)		3.821 (.440)	3.772 (.404)	.12 / 1.3 / -.24, .48 / 7 (58/35)
Quarter Sprint Time (s)	1	3.744 (.335)	3.744 (.306)	.00 / .0 / -.50, .50 / 24 (52/24)
	2	3.849 (.455)	3.797 (.418)	.12 / 1.4 / -.29, .53 / 9 (54/37)
	3	3.860 (.523)	3.794 (.486)	.14 / 1.7 / -.18, .45 / 4 (60/36)
	4	3.829 (.475)	3.753 (.484)	.16 / 2.0 / -.19, .50 / 4 (55/41)
First Sprint Time (s)	1	3.680 (.328)	3.753 (.457)	.16 / 1.9 / -.74, .42 / 45 (40/14)
	2	3.794 (.453)	3.821 (.390)	.07 / .7 / -.07, .32 / 27 (61/12)
	3	3.784 (.469)	3.778 (.482)	.01 / .2 / -.28, .30 / 11 (76/13)
	4	3.835 (.559)	3.772 (.559)	.11 / 1.6 / -.35, .58 / 12 (51/37)
Best Sprint Time (s)	1	3.597 (.255)	3.577 (.300)	.07 / .6 / -.22, .35 / 6 (74/20)
	2	3.709 (.398)	3.720 (.400)	.03 / .3 / -.34, .28 / 17 (72/11)
	3	3.751 (.501)	3.742 (.477)	.02 / .2 / -.25, .29 / 9 (79/12)
	4	3.698 (.429)	3.651 (.432)	.11 / 1.3 / -.17, .39 / 4 (68/28)
Overall Circuit Time (s)		44.53 (4.21)	44.05 (4.13)	.12 / 1.1 / -.17, .40 / 4 (66/30)
Quarter Circuit Time (s)	1	44.67 (3.97)	43.37 (3.25)	.40 / 2.9 / .11, .68 / 0 (12/88)
	2	44.78 (4.24)	44.40 (4.34)	.09 / .8 / -.28, .46 / 9 (62/29)
	3	44.61 (4.51)	44.29 (5.06)	.06 / .7 / -.29, .42 / 10 (65/25)
	4	44.07 (4.88)	44.16 (4.57)	.02 / .2 / -.27, .23 / 11 (82/7)

Where the chance of benefit or harm were both calculated to be > 5%, the true effect was deemed unclear. < 1%, almost certainly not; <5%, very unlikely; <25%, unlikely/probably not; 25-75%, possibly/possibly not; >75%, likely/probably; >95%, very likely; >99%, almost certainly.

Table 2. Mean (± SD) core (T_C; n=10) and mean skin (mean T_{Sk}; n=9) temperature over the baseline period and at the end of each quarter for the precooling (PC) and control (CONT) trials.

		Baseline Period (30 min)		Quarter			
		Start	Finish	1	2	3	4
T_C	PC	37.1 (.3)	36.7 (.4)	38.2 (.4)	38.7 (.6)	38.5 (.7)	38.6 (.6)
	CONT	37.1 (.3)	36.9 (.3) *	38.4 (.3) *	38.8 (.4)	38.6 (.3)	38.6 (.4)
Mean T_{Sk}	PC	31.0 (.8)	31.9 (.6)	33.7 (1.5)	33.4 (1.6)	33.1 (1.5)	32.9 (1.3)
	CONT	30.7 (.9)	31.9 (.8)	33.7 (2.4)	33.4 (2.8)	32.9 (3.1)	33.0 (3.2)

* = moderate Cohen's *d* (0.67; 90% CL = -1.27, 0.23) effect size with PC.

90% CL = -1.27, 0.23) also suggested a lower T_C in PC, compared with CONT, at the end of quarter 1 (Table 2). Mean skin temperature between trials was not different with precooling before exercise and remained relatively stable (~33-34°C) over the exercise protocol (Table 2).

No clear and substantial differences were found for any other physiological variables (HR, RPE or TS; Table 3), however a moderate Cohen's *d* effect sizes (Cohen's *d*=0.67; 90% CL=-0.07, 1.45) suggested a greater amount of sweat loss in PC (2.16 ± 0.23 kg) compared with CONT (1.96 ± 0.30 kg).

Discussion

The purpose of this study was to determine the effect of using a combination of internal and external precooling methods (ice slushy and cooling jacket) simultaneously on repeat-sprint performance, in seasonally acclimatised participants, in warm/dry outdoor conditions. This is the first study to examine the effect of precooling on repeat-sprint performance using a prolonged simulated team-sport protocol in a field setting, thereby providing some ecological validity. The main finding from this study was that despite T_C being lower after the precooling period (Cohen's *d* = 0.67; 90% CL = -1.27, 0.23), repeat-sprint performance was neither clearly nor substantially improved compared with a no cooling (control) trial. In addition, no clear or substantial differences in measures of physiological strain (HR, RPE, TS) were apparent between conditions.

Performance results from the current study are comparable to those of previous research (Duffield and Marino, 2007; Minett et al., 2011), which also found no significant improvement in repeat-sprint performance following precooling. Specifically, Duffield and Marino (2007) and Minett et al. (2011) both used similar running protocols, consisting of 2 x 30-35-min halves of repeat-sprint exercise interspersed with self-paced, sub-maximal activity performed at varying intensities indoors in a heated room with 32-34°C air temperatures and 30-33% RH. In addition, no differences were reported for high speed running distance during a competitive 90 min soccer match performed in warm ambient conditions (29°C and 78% RH; Duffield et al., 2013). According to Duffield and Marino (2007), the lack of improvement in sprint performance may have been due to heat strain not being high enough for precooling to have any significant effect. This explanation may also apply to the results of the current study, where the outdoor air temperature and humidity (with solar radiation), were possibly not high enough to produce greater environmental thermal stress and hence higher heat strain.

In support of the above supposition, studies that have reported significantly improved sprint performance following precooling (Brade et al., 2012; Castle et al., 2006) were performed in a climate chamber, where ambient conditions were somewhat higher (~33-35°C and 51-57% RH) than those of the current study. Comparison of physiological measures showed that mean T_{Sk} values were higher in the studies by Brade et al. (2012) and Castle et al. (2006), being ~34-37°C vs 32-33°C in the present study, while other indicators of thermal strain (such as T_C, HR, RPE and TS), were similar between all of these aforementioned studies and the current one. Possibly, in environmental conditions where high skin temperatures are manifested, such that the core-skin temperature gradient is narrowed, then precooling might become more effective. Furthermore, it should be acknowledged that (in the present study) enhanced heat dissipation, via the avenues of convection and evaporation, as expected in an outdoor environment, would also reduce the levels of heat strain compared to the same exercise done in a climate chamber (Saunders et al., 2005).

In the current study, 30-min of precooling reduced T_C by ~0.4°C while resting in thermoneutral lab conditions. This reduction is greater than reported in previous studies, where a decrease of ~0.2°C after precooling (using an ice bath and vest and whole body cooling) was found by both Duffield and Marino (2007) and Minett et al. (2011), respectively. However, precooling in both of these studies was performed in warm conditions (32-34°C and 30-33% RH), which may have limited the potential

Table 3. Mean (± SD) heart rate (HR), thermal sensation (TS) and rating of perceived exertion (RPE) at the end of each quarter for the precooling (PC) and control (CONT) trials.

		Quarter			
		1	2	3	4
HR	PC	168 (15)	169 (16)	166 (18)	171 (17)
	CONT	166 (20)	167 (16)	168 (14)	171 (12)
TS	PC	5 (1)	6 (1)	6 (1)	6 (1)
	CONT	6 (1)	6 (1)	6 (1)	6 (1)
RPE	PC	15 (2)	16 (2)	16 (1)	17 (1)
	CONT	15 (2)	16 (2)	16 (1)	17 (1)

No clear and/or substantial differences were observed.

reductions in T_C. Notably, the greater decrease in T_C seen after precooling in the current study, did not translate into a markedly lower physiological strain during exercise, as demonstrated by measures of mean T_{Sk}, HR, RPE and TS, which were not different between conditions. In addition, T_C was relatively similar between conditions for the duration of the exercise protocol, other than at the end of quarter 1 when it was ~0.2°C lower in PC. This may further explain the lack of performance benefits in the current study, as the precooling here resulted in no marked reduction of physiological strain measures, which has been evident in other studies that have seen performance enhancements (Arngrimsson et al., 2004; Booth et al., 1997; Duffield et al., 2010; Kay et al., 1999).

Another contributing factor that may have resulted in precooling being ineffective in the current study may be the seasonal heat acclimatisation of the participants; lessening the level of heat strain and potentially attenuating any ergogenic effects. Importantly, heat acclimation/acclimatisation has been reported to be the most reputable and well-studied technique used to counteract the negative effects of heat on exercise performance (Marino, 2002). Recently, both Castle et al. (2011) and Brade et al. (2013) concluded that precooling provided no enhancement to repeat-sprint performance in heat when participants are fully or partially heat acclimated.

Sweat loss in the current study was moderately (~0.2 kg) higher following PC compared to CONT (Cohen's d = 0.67; 90% CL = -0.07, 1.45). This finding is consistent with our earlier work (Brade et al., 2012; 2013) where we proposed that a higher sweat loss in PC may have been due to the ingestion of the ice slushy. Being cold, the ice slushy fluid may move through the body at a faster rate than the same volume of fluid of a higher temperature (Costill and Saltin, 1974), and potentially increase fluid supply to the sweat glands. Commonly, sweat loss is reported to be lower after precooling (Argrimsson et al., 2004; Duffield and Marino, 2007; Duffield et al., 2010; Kay et al., 1999; Minett et al., 2011), but such studies have generally employed only external (rather than internal) cooling methods, such as vests/jackets, ice baths and iced towels. If used in isolation, or in combination with external cooling methods, ice slushy ingestion may produce a higher sweat loss in prolonged, repeated short sprint exercise, but not necessarily confer any performance advantage.

A limitation to the current study is the absence of a non-acclimatised trial (or group). This was excluded from the experimental design because of the logistical considerations of having to wait some months for the winter season, which in turn may have further limited the study via participant changes in training status and the likely increase in participant drop-out. A further limitation to this study relates to the use of a simulated exercise team-sport circuit, as opposed to an actual team-game, where movement patterns and energy use may have been different.

Conclusion

In conclusion, it appears that precooling neither clearly nor substantially enhances repeat-sprint performance in the field in warm conditions in seasonally acclimatised participants. This result may be mostly due to the only moderate levels of heat strain produced here by the warm (as opposed to hot) environmental conditions and/or the fact that participants were seasonally acclimatised. Precooling appears unnecessary if athletes are heat acclimatised/acclimated and environmental conditions are not overly hot or humid. The results of this study further support the notion that acclimatisation/acclimation is a more effective method of protecting against heat strain than precooling.

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Key points

- Pre-cooling did not improve repeated sprint performance during a prolonged team-sport circuit in field conditions.
- If individuals are already heat acclimatised/acclimated, pre-cooling is unnecessary for performance enhancement.
- Acclimation/acclimatisation seems to be the more powerful method for protecting against heat strain.

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