Research article

Physiological and perceptual effects of precooling in wheelchair basketball athletes

Peta Forsyth^{1,2} , Kate Pumpa¹, Emma Knight³, Joanna Miller²

¹Research Institute for Sport and Exercise, University of Canberra, Canberra, ACT, Australia, ²Physiology Department, Australian Institute of Sport, Canberra, ACT, Australia, ³Performance Research, Australian Institute of Sport, Canberra, ACT, Australia

Objective: To investigate the physiological and perceptual effects of three precooling strategies during pre-exercise rest in athletes with a spinal cord injury (SCI).

Design: Randomized, counterbalanced. Participants were precooled, then rested for 60 minutes ($22.7 \pm 0.2^\circ\text{C}$, $64.2 \pm 2.6\%\text{RH}$).

Setting: National Wheelchair Basketball Training Centre, Australia.

Participants: Sixteen wheelchair basketball athletes with a SCI.

Interventions: Participants were precooled through; 1) 10 minutes of 15.8°C cold water immersion (CWI), 2) ingestion of 6.8 g/kg^{-1} of slushie (S) from sports drink; 3) ingestion of 6.8 g/kg^{-1} of slushie with application of iced towels to the legs, torso and back/arms (ST); or 4) ingestion of 6.8 g/kg^{-1} of room temperature (22.3°C) sports drink (CON).

Outcome measures: Core temperature (T_{gi}), skin temperature (T_{sk}), heart rate (HR), and thermal and gastrointestinal comfort.

Results: Following CWI, a significant reduction in T_{gi} was observed compared to CON, with a greatest reduction of 1.58°C occurring 40 minutes post-cooling (95% CI [1.07, 2.10]). A significant reduction in T_{gi} following ST compared to CON was also observed at 20 minutes (0.56°C ; [0.03, 1.09]) and 30 minutes (0.56°C ; [0.04, 1.09]) post-cooling. Additionally, a significant interaction between impairment level and time was observed for T_{gi} and HR, demonstrating athletes with a higher level of impairment experienced a greater reduction in HR and significant decrease in rate of decline in T_{gi} , compared to lesser impaired athletes.

Conclusion: CWI and ST can effectively lower body temperature in athletes with a SCI, and may assist in tolerating warm conditions.

Keywords: Body temperature regulation, Cooling, Paraplegia, Spinal cord injuries, Thermoregulation

Introduction

Maintaining performance in hot and humid conditions is a challenge that many athletes face. For individuals with a spinal cord injury (SCI), diminished autonomic nervous system control over vasomotor and sudomotor responses impairs their ability to dissipate body heat.¹ As the degree of paralysis experienced is directly associated with the level and completeness of the spinal lesion,² a more severe SCI may pose a greater challenge to thermoregulation. When exercising in environmental conditions of high ambient temperature and relative humidity (RH), the body may not be able to dissipate heat at the rate it is produced internally, thus increasing

the risk of heat-related illness. Despite the lack of supporting research, recommendations advise individuals with a SCI to minimise exposure to temperatures $>21^\circ\text{C}$ and 50% RH while exercising due to the increased thermal strain that these environmental conditions may induce.³ In many wheelchair-based sports, athletes with a SCI regularly train and compete in conditions exceeding these recommendations, emphasizing the need to implement appropriate strategies, such as precooling.

Precooling is an effective strategy to combat the metabolic and environmental heat gained during exercise.⁴ By implementing a cooling strategy prior to exercise, body temperature can be lowered, thereby enabling a greater capacity for heat storage. For athletes exercising in the heat, being able to tolerate greater gains in

Correspondence to: Peta Forsyth, C/- Physiology Department, Australian Institute of Sport, Leverrier Street, ACT, Australia, 2617. Email: peta.forsyth@ausport.gov.au

environmental and metabolic heat before a critical limiting temperature is reached, can help to maintain performance.⁵ A large body of research recognizes the performance benefits of a range of precooling strategies⁴ for intermittent^{6,7} and endurance exercise^{8–10} in hot conditions (30–34°C, 33–75% RH). However, the majority of literature investigating these strategies has been conducted with able-bodied athletes, with limited consideration for its impact on, or application to, athletes with a SCI.

The majority of cooling research involving individuals with a SCI has focused on site-specific cooling during, rather than prior to exercise.¹¹ One study reported that wearing a foot cooling device during 45 minutes of arm-cranking exercise at 66% peak oxygen uptake resulted in a significantly lower aural temperature and heart rate than when no cooling strategy was used in a hot environment (32°C, 25% RH).¹² This strategy may be appropriate for ergometer-based training sessions; however its utility in field-based settings is limited. Another investigation established that wearing either a refrigerated headpiece or cooling vest was ineffective at reducing mean body heat storage during 30 minutes of wheelchair ergometer exercise (16.5 km/hr). The metabolic heat generated during exercise under 33°C and 75% RH far exceeded the cooling potential of either device (266 W for the headpiece and 388 W for the vest),¹³ suggesting that some cooling strategies implemented during exercise may not always possess the cooling capacity required to effectively reduce heat strain. Instead, a combination of strategies or a more powerful strategy may be necessary to combat exercise-induced heat strain in individuals with a SCI. In contrast to the aforementioned investigations, Webborn *et al.*¹⁴ observed a lower gastrointestinal temperature (T_{gi}) and increased time to exhaustion when athletes with a SCI wore a cooling vest either before or during intermittent arm-cranking exercise in the heat (32°C, 50% RH). The discrepancy in results across studies may be due to differences in exercise methodology, participant demographics, and/or timing of exposure to the cooling medium. These studies highlight the limited application of cooling strategies with individuals with a SCI. Furthermore, it is not always achievable to implement cooling strategies immediately prior to exercise in a competition setting due to preparation priorities (e.g. warm-up, team meeting), highlighting the need to identify strategies that may be suitable to use further out from the commencement of exercise.

With the current understanding of thermoregulatory impairment in this population¹⁵ and the established

benefits of precooling in able-bodied athletes, the use of precooling with athletes with a SCI is a compelling and necessary area of investigation. Many strategies such as cold water immersion, slushie ingestion, and the application of cold garments/towels have reduced thermoregulatory strain and improved performance in able-bodied populations⁴; however these are yet to be explored in individuals with a SCI. Furthermore, the effects of precooling in able-bodied persons are typically maintained only for 30–40 minutes,^{16,17} however it is not yet understood how long the effects of precooling can be maintained in those with a SCI. Before assessing the effectiveness of precooling with performance measures in this population, it is worthwhile to establish which strategies effectively reduce physiological parameters, and to what magnitude. This will allow for an understanding into how long the effects of the different cooling methods can last and inform when each method should be applied prior to competition. Therefore, the present study aimed to investigate the physiological and perceptual effects of cold water immersion, slushie ingestion, and a combined strategy involving the ingestion of a slushie while iced towels are externally applied to the legs, torso, back and arms on wheelchair basketball athletes with a SCI during 60 minutes of pre-exercise rest to determine how long the effects of each intervention last. The CWI protocol was chosen due to the participants' familiarity with it for post-exercise recovery, and slushies were chosen due to them being simple to implement with individuals with a SCI, who have reduced motor movement. The addition of cold towels to the slushie protocol was chosen as towels are often available in a practical setting and may provide additional cooling.

Method

Subjects

Sixteen national-level wheelchair basketball athletes volunteered to participate in the present study (Table 1); 14 males [mean ($\pm$ SD), age 25.3 $\pm$ 4.4 years, mass 75.67 $\pm$ 14.10 kg, sum of four skinfolds (tricep, bicep, subscapularis and abdomen) 45.6 $\pm$ 20.5 mm], and two females [age 29.9 $\pm$ 3.5 years, mass 66.17 $\pm$ 2.48 kg, sum of four skinfolds 73.2 $\pm$ 8.6 mm]. Participants were grouped by impairment level based on the International Wheelchair Basketball Federation classification system: athletes with high paraplegia (HP) were classified as 1.0, 1.5, or 2.0 point players, and athletes with low paraplegia (LP) were classified as 2.5, 3.0, or 3.5.¹⁸ The group contained nine HP athletes and seven LP athletes. Participants were members of the Australian Wheelchair Basketball Squad, and had

Table 1 Participant demographics

Participant	Age (Years)	Body Mass (kg)	Sum of 4 skinfolds (mm)	Injury	Injury Level	Years Since Injury	Classification
1	31	58.86	52.2	Complete paraplegia	L1	25	1
2	29	56.04	19.9	Complete paraplegia	T10	6	1.5
3	29	68.16	35.1	Complete paraplegia	T4	10	1
4	21	66.4	19.5	Complete paraplegia	T6-T7	4	1
5	23	85.5	59.4	Complete paraplegia	C7-T1	5	1
6	28	102.84	60.1	Complete paraplegia	T5-T6	3	1
7	25	85.26	63.2	Complete paraplegia	T5	4	1.5
8	22	86.22	71.3	Spina Bifida	-	22	2.5
9	21	74.12	59.3	Complete paraplegia	T12	5	2
10	21	81.48	65.5	Spastic Paraparesis	-	21	2.5
11	32	77.94	37.0	Incomplete paraplegia	T10-T11	7	2
12	25	52.3	18.0	Spinal cord thinning	T2-T6	25	3
13	28	92.38	87.2	Incomplete paraplegia	T11-T12	25	3
14	16	57.08	34.3	Arthrogryposis	-	16	3
15	26	65.36	82.9	Incomplete paraplegia	L1	9	3
16	29	64.2	70.4	Spina Bifida	-	29	3.5
Mean ($\pm$ SD)	25.4 (4.4)	73.38 (14.64)	52.21 (22.29)			13.5 (9.4)	

Control (CON), cold water immersion (CWI), slushies (S), slushies and towels (ST)

played competitively for at least three years. All participants provided written informed consent, and ethical approval was granted from the Human Ethics Committee at the Australian Institute of Sport and the University of Canberra.

Design

Data were collected on four consecutive days during a training camp. Using a counterbalanced cross-over design (Williams design for four treatments)¹⁹; participants were randomised to one of four treatment sequences, and completed one intervention on each day of the camp. Participants refrained from exercise in the 12 hours before each trial. The precooling interventions included cold water immersion (CWI), slushie ingestion (S), a combination of slushie ingestion with the external application of iced towels (ST) and a control condition (CON). Participants began precooling at the same time each day with baseline measures collected following 20 minutes of passive rest. The duration of the precooling period was 20 minutes (except in the case of CWI), and was immediately followed by 60 minutes of passive rest, both which occurred in a temperature-controlled room ($22.7 \pm 0.2^{\circ}\text{C}$, $64.2 \pm$

2.6% RH). Caffeine intake prior to the trial was not controlled for, however during the trial participants refrained from all fluid consumption other than what was specified in each intervention. Participants completed the CWI and ST interventions in shorts and no shirt. During the CON and S intervention, as well as during the passive rest period following all interventions, participants wore their typical training attire of a basketball singlet and shorts.

Interventions

Participants completed all interventions while seated. The S intervention involved the ingestion of 6.8 g/kg^{-1} of slushie,⁹ administered in two 3.4 g/kg^{-1} boluses provided 10 minutes apart to ensure consistent ingestion. The ST intervention replicated the S protocol with the addition of three iced towels applied to the legs, torso, and back/arms,⁸ and each towel was rotated every 3 minutes during the final 10 minutes of precooling. Towels were only used during the final 10 minutes of the 20 minutes precooling period to create a less arduous and realistically achievable protocol for a team in a practical environment. During CWI, participants completed full-body immersion excluding head and

neck ($15.8 \pm 0.1^\circ\text{C}$) for 10 minutes and consumed 6.8 g/kg^{-1} of room temperature sports drink ($22.3 \pm 0.3^\circ\text{C}$). The commencement of CWI occurred 10 minutes into the precooling period such that all interventions were completed by the start of the 60-minute passive rest period. In the CON condition, participants ingested

room temperature sports drink matched for volume⁹ and rested passively for 20 minutes.

Outcome measures

Physiological measures included core temperature (T_{gi}), skin temperature and heart rate (HR). Core temperature was recorded every 5 minutes throughout each trial using a telemetric pill (HQ, USA) to measure temperature in the gastrointestinal tract. The pill was ingested eight hours before the commencement of each trial to ensure progression past the stomach, and therefore not influenced by subsequent fluid ingestion.¹⁴ Skin temperature was continuously measured throughout each trial using iButton sensors (Maxim, USA), secured to the right hand side of the body. The sensors were fixed to the chest, forearm, thigh and calf before each trial using adhesive tape, and these sites were used to calculate mean skin temperature (T_{sk}).²⁰ Surgical pens marked the sites to ensure consistent placement for subsequent trials. Heart rate was continuously recorded from 5 minutes prior to, and throughout each trial (Suunto, Vantaa, Finland).

Figure 1 Mean changes in core body temperature (A), mean skin temperature (B) and heart rate (C) during precooling and passive rest. * Significant difference between CWI and CON, # significant difference between CWI and S, † significant difference between CWI and ST, § significant difference between ST and CON, ⊥ significant difference between ST and S. Data are presented as mean $\pm$ confidence intervals. Statistical significance set at $P < 0.05$. Control (CON), cold water immersion (CWI), slushies (S), slushies and towels (ST).

Figure 2 Mean changes in core body temperature (A) and heart rate (B) by impairment level during precooling and passive rest. * Significant reduction within HP group, † significant reduction within LP group, # significant difference between HP group and LP group. Data are presented as mean $\pm$ confidence intervals. Statistical significance set at $P < 0.05$. High paraplegics (HP), low paraplegics (LP).

Perceptual measures were recorded every 5 minutes throughout each trial. Thermal comfort was assessed on a scale of zero (unbearably cold) to eight (unbearably hot).²¹ A five-point scale assessed gastrointestinal comfort,⁸ and was selected to evaluate whether slushie volume was practically suitable for this population.

Statistical analyses

To investigate the effects of each treatment over the 20-minute precooling period and 60 minutes of passive rest, linear mixed models were fitted for T_{gi} , T_{sk} , HR, thermal and gastrointestinal comfort. Time point (0, 10, 20, 30, 40, 50, 60, 70, and 80 minutes), treatment, impairment level, and their interactions were fitted as fixed effects. The baseline value for each trial within participant was also fitted as a fixed effect. Participant, and trial within participant, were fitted as random effects to account for correlation of repeated measures within trials within participants. The significance of the fixed effects was examined using F-tests, and non-significant terms ($P > 0.05$) were removed from the models. Tukey's HSD post-hoc analysis was used to identify differences. Estimated means and 95% confidence intervals are reported. All statistical analyses were performed with JMP statistical software (version 12, SAS Institute Inc., Cary, NC, USA).

Figure 3 Mean perceptual ratings of gastrointestinal comfort during precooling and passive rest. *Significant difference within ST group compared to ST at 20 minutes, # significant difference within ST group compared to ST at 10 minutes. Data are presented as mean $\pm$ confidence intervals. Statistical significance set at $P < 0.05$.

Results

For T_{gi} , a significant interaction was observed between time and treatment ($F_{24,457.3} = 24.66$, $P < 0.0001$) indicating that the change in T_{gi} over time differed between treatments (Fig. 1A). Following CWI, mean T_{gi} was significantly lower than CON from 30 minutes onwards, and significantly lower than S and ST from 40 minutes onwards. The largest differences were observed at 60 minutes; the mean T_{gi} for CWI was 1.58°C (95% CI [1.07, 2.10]) lower than CON, 1.46°C (0.95, 1.97) lower than S, and 1.10°C (0.58, 1.61) lower than ST. Furthermore, mean T_{gi} was significantly lower following ST than CON at 40 minutes (0.56°C ; [0.03, 1.09]), and 50 minutes (0.56°C ; [0.04, 1.09]). Additionally, a significant interaction between impairment level and time was observed ($F_{8,457.3} = 4.08$, $P = 0.0001$). There was a greater decrease in T_{gi} over time for the HP group than the LP group (Fig. 2A).

A significant interaction was observed in T_{sk} between time and treatment ($F_{24,416} = 60.22$, $P < 0.0001$; Fig. 1B). Treatments that involved an external form of cooling resulted in significant reductions in T_{sk} . Mean skin temperature was significantly lower following CWI than CON and S from 10 minutes onwards. Following ST, T_{sk} was also significantly lower than CON from 20 minutes onwards, and S from 20–60 minutes. The greatest reductions in T_{sk} occurred at 20 minutes, with CWI declining 14.00°C (12.55, 15.45) lower than CON, and ST declining 6.02°C (4.74, 7.30) lower than CON. Mean skin temperature was also significantly lower for CWI than ST from 20 minutes onwards, with the greatest difference occurring at 20 minutes (7.98°C ; [6.51, 9.45]).

For HR, a significant interaction was observed between time and treatment ($F_{24,416} = 6.28$, $P < 0.0001$), demonstrating that HR responses to treatments were different across time (Fig. 1C). Mean HR was significantly higher at 10 minutes during CWI compared to CON by 15.2 bpm (4.4, 25.0), however became significantly lower at 50 minutes (10.9 bpm; [0.1, 21.7]), 70 minutes (10.8 bpm; [0.01, 21.6]), and 80 minutes (17.0 bpm; [6.2, 27.8]). A similar pattern for the change in mean HR over time was observed between CWI and S, with HR being significantly higher during CWI at 10 minutes (11.9 bpm; [0.9, 22.9]), and significantly lower at 70 minutes (12.9 bpm; [1.9, 23.9]), and 80 minutes (14.6 bpm; [3.6, 25.6]). Additionally, there was a significant interaction between time and impairment level ($F_{8,416} = 4.45$, $P < 0.0001$; Fig. 2B). The reduction in HR over time was greater in the HP group, with mean HR significantly lower for the HP than the LP group at 40 minutes (10.8 bpm [0.4, 21.3]).

An interaction between time and treatment was observed for ratings of thermal comfort ($F_{24,480} = 14.80$, $P < 0.0001$). Significantly lower mean thermal comfort ratings were observed following all precooling interventions compared to CON from 10–30 minutes, however only CWI remained significantly lower compared to CON between 40–60 minutes. Additionally, ratings of thermal comfort were significantly lower for CWI compared to S at 10 minutes and from 40–60 minutes, and compared to ST at 10 minutes and from 30–50 minutes. The difference in mean thermal comfort ratings compared to CON were lowest for CWI at 10 minutes (2.6; [2.0, 3.3]), ST at 20 minutes (2.2; [1.6, 2.8]), and S at 20 minutes (1.4; [0.8, 2.0]).

An interaction between treatment and time was also observed in ratings of gastrointestinal comfort ($F_{24,480} = 2.09$, $P = 0.0021$). The only significant differences observed occurred within ST. Ratings of gastrointestinal comfort during ST were significantly higher at 10 minutes compared to 50–80 minutes, and at 20 minutes compared to baseline, and 30–80 minutes. However at every time point, mean gastrointestinal comfort ratings were within a ‘comfortable’ range (Fig. 3).

Discussion

This research examined the physiological and perceptual effects of three precooling strategies on national-level wheelchair basketball athletes with a SCI, to understand how long the effects of each intervention last prior to exercise. Cold water immersion produced the greatest cooling effect, exhibiting the largest reductions in T_{gi} and T_{sk} . The ingestion of a slushie had limited physiological impact; however when combined with the application of iced towels, T_{sk} was significantly reduced throughout passive rest, and T_{gi} reduced at 20 and 30 minutes post-cooling.

A strong body of evidence supports the effectiveness of CWI as a strategy for reducing T_{gi} and T_{sk} prior to exercise in hot conditions with able-bodied athletes using various immersion temperatures and depths.^{10,22,23} The present CWI protocol immersed the majority of the body’s surface area, resulting in large reductions in T_{gi} and T_{sk} , both of which were significantly reduced throughout the passive rest period. When CWI commenced, a tachycardia associated with the cold-shock response was observed, followed by a significant decrease in HR, which is representative of existing literature.²⁴ Furthermore, at 20 minutes following CWI, the reduction in HR was significantly greater for HP compared to LP, demonstrating that level of impairment influences physiological responses following CWI.

Despite CWI being highly effective for reducing physiological parameters, adequate facilities may not always be available. The ST combination as a precooling intervention has resulted in a physiological and performance benefit in able-bodied athletes,⁸ providing an alternative when CWI is not feasible. However, the slushie/towel protocol must be carefully considered as Ross *et al.*⁸ utilized an application procedure that may not be achievable with many athletes at once (e.g. team sports), and a slushie volume that is potentially too large for some individuals with a SCI. Therefore, the protocol for this study was modified by reducing the slushie volume by half (14 g/kg⁻¹ to 6.8 g/kg⁻¹) and applying iced towels for 10 minutes instead of 20 minutes, to investigate if this combination remained an effective precooling strategy in athletes with a SCI. Interestingly, at the completion of precooling, T_{gi} had decreased by approximately 0.25°C (non-significant), a similar decline to that observed by Ross *et al.*⁸ Mean skin temperature was significantly lower compared to CON at the conclusion of precooling until the completion of passive rest, however T_{gi} was only significantly lower 20 and 30 minutes post-cooling. The afterdrop in T_{gi} that occurs when the body’s periphery is cooled,²⁵ may not have been as pronounced with ST due to a lesser reduction in T_{sk} as a result of a smaller thermal gradient between the skin and towels, compared to CWI. In addition, the towels only partially covered body surface area, thus limiting cooling potential.

The ingestion of a slushie alone has been identified as an effective modality to reduce body temperature prior to exercise in able-bodied individuals,^{9,26,27} however, the present study did not observe such changes. Many individuals with a SCI have a lower body mass due to musculoskeletal atrophy below the spinal lesion,²⁸ and may therefore consume a lower absolute volume of slushie. Although the volume of slushie consumed in the present study was well-tolerated, it was too small to elicit a significant decline in T_{gi} . Despite being non-significant, the reduction in T_{gi} observed following the ingestion of the slushie suggests that this volume may still be beneficial as a precooling intervention if exercise begins immediately after ingestion, however further research is required to investigate this. The effect of ingesting larger volumes of slushie has been investigated in able-bodied athletes.^{8,27} However, increasing the slushie volume should be approached with caution for individuals with a SCI > T6 as they are at increased risk of autonomic dysreflexia, and overfilling the urinary bladder may trigger its onset.²⁹ In the present study, three athletes had a SCI above T6 and no episodes of autonomic dysreflexia occurred with 6.8 g/kg⁻¹. If

slushie volume was to be increased in athletes with an injury below T6, it may be worthwhile to prescribe slushie volumes normalised for torso mass, as opposed to total body mass. When iced beverages are ingested, the ice acts as a heat sink within the body and temperature is lowered as the cold stimulus in the gastrointestinal tract equilibrates with surrounding tissues,⁴ suggesting the cooling from a slushie occurs in the torso region. The efficacy of cooling athletes with a SCI with slushies requires further investigation, though researchers should be mindful of the symptoms associated with autonomic dysreflexia and consider individualizing protocols based on the severity of a SCI.

Due to individual differences in autonomic nervous system control, the literature recommends prescribing cooling strategies based on the level and completeness of SCI.^{2,30} Individuals with a higher lesion have a reduced body surface area that can maintain thermoregulation when exposed to a cooling medium through vasomotor adjustments and shivering. In the present study, a significant reduction in T_{gi} was observed in the HP group following the start of immersion and for the first 10 minutes of passive rest; however this reduction was non-significant for the LP group. The greater reduction in HP athletes supports the notion that those with a higher degree of impairment may have a reduced ability to thermoregulate when exposed to a cooling medium. This further supports the recommendations to consider the level of an individual's SCI when prescribing cooling strategies prior to exercise.

Precooling is implemented before exercise in warm conditions, ultimately to improve performance. The use of CWI for precooling has demonstrated effectiveness at decreasing body temperature and improving performance in the heat with able-bodied athletes,^{22,23,31} however the impact of CWI on exercise performance in athletes with a SCI remains unknown. It can be hypothesized that the significant reduction in T_{sk} , T_{gi} and HR observed following 10 minutes full-body CWI may have the potential to improve performance, however further research is necessary. Future research should also consider the level of a SCI on physiological responses to precooling, and the potential for such differences to influence performance.

Conclusion

The present study identifies CWI as the most effective strategy to reduce T_{gi} , T_{sk} and HR in wheelchair basketball athletes with a SCI. The combination of slushies and towels was also effective; however a more transient change in physiological variables was observed when compared to the CWI trial. In addition, a non-

significant reduction in T_{gi} and HR was observed following the ingestion of a slushie. Based on this information, it could be hypothesized that these strategies may be beneficial to assist individuals with a SCI tolerate exercise in warm environmental conditions. For the purpose of precooling, it may be necessary to implement cooling with ST and S closer to the commencement of exercise than when using CWI due to differences in how long the cooling effects last. For example, if precooling with slushies, it may be best to begin exercise immediately after ingestion due to the transient reduction in T_{gi} . Conversely, CWI may still be effective if completed up to 40–60 minutes before exercise. Due to the lack of a performance measure, conclusions cannot be made regarding whether each precooling intervention can improve performance without further investigation. Future research should investigate the impact of precooling on specific performance outcomes in warm conditions to ascertain whether the observed physiological changes enhance performance.

The present study also demonstrated that the rate at which T_{gi} reduced following precooling was different depending on the level of impairment. The reduction in T_{gi} in HP occurred at a significant rate following precooling, suggesting that those with a higher spinal cord lesion may require less exposure to a cooling medium than individuals with a lower lesion. Future research may also consider the method and duration of cooling based on lesion level in order to optimize precooling protocols in athletes with a SCI.

Disclaimer statements

Contributors None.

Funding The authors wish to acknowledge that funding for this project was provided by the University of Canberra Faculty of Health Grants Program.

Conflicts of interest None.

Ethics approval None.

ORCID

Peta Forsyth <http://orcid.org/0000-0001-8252-6230>

References

- 1 Sawka MN, Latzka WA, Pandolf KB. Temperature regulation during upper body exercise: able-bodied and spinal cord injured. *Med Sci Sports Exerc* 1989;21(5):S132–40.
- 2 Price MJ, Campbell IG. Effects of spinal cord lesion level upon thermoregulation during exercise in the heat. *Med Sci Sports Exerc* 2003;35(7):1100–7.
- 3 Bhambhani Y. Physiology of wheelchair racing in athletes with spinal cord injury. *Sports Med* 2002;32(1):23–51.
- 4 Ross M, Abbiss C, Laursen P, Martin D, Burke L. Precooling methods and their effects on athletic performance. *Sports Med* 2013;43(3):207–25.

- 5 González-Alonso J, Teller C, Andersen SL, Jensen FB, Hyldig T, Nielsen B. Influence of body temperature on the development of fatigue during prolonged exercise in the heat. *J Appl Physiol* 1999;86(3):1032–9.
- 6 Minett GM, Duffield R, Marino FE, Portus M. Volume-dependent response of precooling for intermittent-sprint exercise in the heat. *Med Sci Sports Exerc* 2011;43(9):1760–9.
- 7 Castle PC, Macdonald AL, Philp A, Webborn A, Watt PW, Maxwell NS. Precooling leg muscle improves intermittent sprint exercise performance in hot, humid conditions. *J Appl Physiol* 2006;100(4):1377–84.
- 8 Ross M, Garvican LA, Jeacocke NA, Laursen PB, Abbiss CR, Martin DT, *et al.* Novel precooling strategy enhances time trial cycling in the heat. *Med Sci Sports Exerc* 2011;43(1):123–33.
- 9 Ihsan M, Landers G, Brearley M, Peeling P. Beneficial effects of ice ingestion as a precooling strategy on 40-km cycling time-trial performance. *Int J Sports Physiol Perform* 2010;5(2):140–51.
- 10 Duffield R, Green R, Castle P, Maxwell N. Precooling can prevent the reduction of self-paced exercise intensity in the heat. *Med Sci Sports Exerc* 2010;42(3):577–84.
- 11 Griggs KE, Price MJ, Goosey-Tolfrey VL. Cooling athletes with a spinal cord injury. *Sports Med* 2015;45(1):9–21.
- 12 Hagobian T, Jacobs K, Kiratli B, Friedlander A. Foot cooling reduces exercise-induced hyperthermia in men with spinal cord injury. *Med Sci Sports Exerc* 2004;36(3):411–7.
- 13 Armstrong LE, Maresh CM, Riebe D, Kenefick RW, Castellani JW, Senk JM, *et al.* Local cooling in wheelchair athletes during exercise-heat stress. *Med Sci Sports Exerc* 1995;27(2):211–6.
- 14 Webborn N, Price M, Castle P, Goosey-Tolfrey V. Effects of two cooling strategies on thermoregulatory responses of tetraplegic athletes during repeated intermittent exercise in the heat. *J Appl Physiol* 2005;98(6):2101–7.
- 15 Price MJ. Thermoregulation during exercise in individuals with spinal cord injuries. *Sports Med* 2006;36(10):863–79.
- 16 Hessemer V, Langusch D, Bruck L, Bodeker R, Breidenbach T. Effect of slightly lowered body temperatures on endurance performance in humans. *J Appl Physiol* 1984;57(6):1731–7.
- 17 Wilson TE, Johnson SC, Petajan JH, Davis SL, Gappmaier E, Luetkemeier MJ, *et al.* Thermal regulatory responses to submaximal cycling following lower-body cooling in humans. *Eur J Appl Physiol* 2002;88(1–2):67–75.
- 18 International WBF. Official player classification manual 2014 (accessed 14 October 2014). http://www.iwbf.org/images/a_classification/ClassificationManual2014--2018EnglishFinal.pdf
- 19 Williams E. Experimental designs balanced for the estimation of residual effects of treatments. *Aust J Chem* 1949;2(2):149–68.
- 20 Ramanathan N. A new weighting system for mean surface temperature of the human body. *J Appl Physiol* 1964;19(3):531–3.
- 21 Young A. Thermal sensations during simultaneous warming and cooling at the forearm: a human psychophysical study. *J Therm Biol* 1987;12(4):243–7.
- 22 Siegel R, Maté J, Watson G, Nosaka K, Laursen PB. Pre-cooling with ice slurry ingestion leads to similar run times to exhaustion in the heat as cold water immersion. *J Sports Sci* 2012;30(2):155–65.
- 23 Booth J, Marino F, Ward JJ. Improved running performance in hot humid conditions following whole body precooling. *Med Sci Sports Exerc* 1997;29(7):943–9.
- 24 Schniepp J, Campbell T, Powell K, Pincivero D. The effects of cold-water immersion on power output and heart rate in elite cyclists. *J Strength Cond Res* 2002;16(4):561–6.
- 25 Romet T. Mechanism of afterdrop after cold water immersion. *J Appl Physiol* 1988;65(4):1535–8.
- 26 Siegel R, Mate J, Brearley MB, Watson G, Nosaka K, Laursen PB. Ice slurry ingestion increases core temperature capacity and running time in the heat. *Med Sci Sports Exerc* 2010;42(4):717–25.
- 27 Stevens CJ, Dascombe B, Boyko A, Sculley D, Callister R. Ice slurry ingestion during cycling improves Olympic distance triathlon performance in the heat. *J Sports Sci* 2013;31(12):1271–9.
- 28 Jacobs PL, Nash MS. Exercise recommendations for individuals with spinal cord injury. *Sports Med* 2004;34(11):727–51.
- 29 Theisen D. Cardiovascular determinants of exercise capacity in the Paralympic athlete with spinal cord injury. *Exp Physiol* 2012;97(3):319–24.
- 30 Griggs KE, Price MJ, Goosey-Tolfrey VL. Cooling athletes with a spinal cord injury. *Sports Med* 2015;45(1):9–21.
- 31 Kay D, Taaffe D, Marino F. Whole-body pre-cooling and heat storage during self-paced cycling performance in warm humid conditions. *J Sports Sci* 1999;17(12):937–44.