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Effects of cooling before and during simulated match play on thermoregulatory responses of athletes with tetraplegia

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Abstract

Objectives: Athletes with high level spinal cord injuries (tetraplegia) are under greater thermal strain during exercise than the able-bodied. The purpose of this study was to investigate the effectiveness of pre-cooling using an ice vest and the combination of pre-cooling and cooling during play using water sprays in athletes with tetraplegia.

Design: Balanced, cross-over design.

Methods: Eight wheelchair rugby players with tetraplegia completed a 60 min intermittent sprint protocol (ISP) on a wheelchair ergometer in 20.2 °C ± 0.2 °C and 33.0 % ± 3.1 % relative humidity. The ISP was conducted on three occasions; no cooling (NC), pre-cooling with an ice vest (P) and pre-cooling with an ice vest and water sprays between quarters (PW). Gastrointestinal (T_{gi}) temperature, mean skin temperature (T_{sk}) and perceptual responses were measured throughout.

Results: At the end of pre-cooling, the change in T_{gi} was not significantly different between conditions ($P>0.05$) but the change in T_{sk} was significantly greater in P and PW compared to NC ($P<0.001$). The change in T_{gi} over the ISP was significantly lower in PW and P compared to NC ($P<0.05$), whilst the change in T_{sk} was lower in PW compared to P and NC ($P<0.05$). Cooling had no effect on performance or perceptual responses ($P>0.05$).

Conclusions: Water spraying between quarters combined with pre-cooling using an ice vest lowers thermal strain to a greater degree than pre-cooling only in athletes with tetraplegia, but has no effect on simulated wheelchair rugby performance or perceptual responses.

Keywords: Spinal cord injuries; sports for persons with disabilities; body temperature regulation; exercise physiology; water sprays; ice vest

Introduction

Individuals with a spinal cord injury (SCI) have a loss of both sweating capacity and vasomotor control below the level of their spinal cord lesion [1,2]. The magnitude of the resulting thermoregulatory impairment is proportional to the level and completeness of the lesion [3]. Consequently, individuals with high level lesions (tetraplegia) are under greater thermal strain than individuals with lower level lesions (paraplegia) and the able-bodied during exercise [3,4].

The use of cooling methods has received considerable interest in the able-bodied athletic population [5], especially when applied as a pre-cooling strategy for reducing thermoregulatory strain, thus, delaying the onset of thermally induced fatigue [6]. It is generally accepted that pre-cooling elicits a performance improvement for endurance or intermittent exercise [5,7,8], yet similar benefits are not found for sprint exercise [8]. Alternatively, cooling during exercise/rest periods, to increase the dissipation of heat gained from environmental or metabolic sources, or a combination of strategies (e.g. pre-cooling and during exercise) may be just as effective as pre-cooling in improving performance [9].

Although athletes with tetraplegia experience a heightened thermal response during exercise compared to the able-bodied, [3] to date eleven studies [10-20] have addressed the application of cooling methods in individuals with a SCI [21]. Webborn et al. [10,14] investigated the use of ice vests prior to and during an intermittent arm-cranking protocol resulting in a lowered gastrointestinal temperature and increased time to exhaustion compared to no cooling. Yet, the protocol's sports specificity to wheelchair court sports could be questioned, as thermoregulatory differences have been shown to exist between arm-cranking and wheelchair propulsion [22]. Furthermore, wearing an ice vest during exercise may be considered impractical due to the size, weight and coverage of a garment. Wheelchair rugby players with tetraplegia, for instance, use water sprays during matches to cool themselves in an attempt to mimic the sweat response of an able-bodied individual. Only one study in wheelchair basketball players with paraplegia[17] has investigated the effectiveness of this cooling method, which was ineffective in attenuating thermal and cardiovascular strain. However, these findings may be partly due to the lack of ecological validity of the incremental arm-cranking protocol used.

Given the limitations in existing research, the purpose of this study was to investigate pre-cooling and the combination of pre-cooling and cooling during breaks in play, on simulated WCR match-play in athletes with tetraplegia. It was hypothesised firstly, that pre-cooling would reduce gastrointestinal temperature (T_{gi}) and mean skin temperature (T_{sk}) compared to no cooling after the cooling period and during the first half of the simulated match -play. Secondly, it was hypothesised that the combination of cooling both pre and during exercise would result in lower T_{sk}, but there would be no further reduction in T_{gi} during match -play when compared to pre-cooling only and no cooling. An ice vest was used as a pre-cooling strategy and water sprays were used during breaks in play, both of which are currently used by wheelchair athletes with tetraplegia.

Methods

Eight highly trained WCR players with tetraplegia (7 male, 1 female, C5/C6- C7) participated in this study (age 32 ± 7 years; body mass 64.0 ± 6.8 kg; sum of skinfolds 52.4 ± 24.3 mm; $\dot{V}O_{2peak}$ 1.35 ± 0.27 $L.min^{-1}$). Participants gave their written informed consent to participate, which was approved by the University Research Ethics Committee.

On the first visit to the laboratory, skinfold measurements (Harpenden Skinfold Callipers, Baty International, West Sussex, UK) were taken from the biceps, triceps, subscapular and suprailliac to calculate the sum of skinfolds (mm). Following this, a wheelchair incremental test to determine peak oxygen uptake ($\dot{V}O_{2peak}$) was completed on a motorised treadmill (HP Cosmos, Traunstein, Germany) at a constant 1.0 % gradient as described by Leicht and colleagues [23]. In brief, the speed was continually increased by 0.2-0.4 $m \cdot s^{-1}$ every 3 min, dependent on the participant's level of lesion, with a slower starting speed and smaller speed increments adopted for players with higher lesion levels. The test was terminated when participants were unable to maintain the speed of the treadmill.

The remaining three visits; two cooling conditions and a no cooling condition, were conducted, at least 24 h apart, and involved an intermittent wheelchair sprint protocol (ISP) in 20.2 ± 0.2ºC and 33.0 ± 3.1% relative humidity. These ambient conditions represented those of an indoor sporting arena that wheelchair rugby players would typically compete in. Conditions were completed in a balanced, cross-over design and each participant served as their own control. Participants were instructed to refrain from alcohol, caffeine and strenuous exercise 24 h prior to each condition.

Participants ingested a telemetry pill (HQ Inc, Palmetto, Florida) for the measurement of T_{gi},, ~6-8 h prior to each condition. Upon arrival, participants were weighed to the nearest 0.1kg (Detecto, Cardinal Scale Manufacturing Co., Webb City, Missouri, USA). Participants transferred into their sports wheelchair and rested for 15 min before completing a 20 min warm-up on the wheelchair ergometer (WERG, VP Handisoft-25, Medical Developpment Hef Groupe, Andreziuex Boutheon, France). The warm-up consisted of 3 min of self-selected low intensity pushing and stretching, followed by two 5 min structured exercise blocks interspersed with 2 min of active recovery and stretching. These structured exercise blocks consisted of 6 cycles of activity, during each cycle the player performed forwards and backwards pushing for 15 s, a 10 s sprint, followed by 30 s of active recovery. Following the second 2 min of active recovery three maximum effort 15 s sprints interspersed with 45 s of active recovery were conducted. The highest maximum speed achieved in these 15 s sprints was used to determine the speed zones (20%, 50%, 60% and 75% of maximum speed) of the subsequent ISP.

A game of wheelchair rugby consists of four 8 minute quarters with the game clock stopped during any stoppages or when the ball is out of play. The ISP aimed to represent a WCR match based on pilot work and data previously collected during competitive match-play by an indoor tracking system (Ubisense, Cambridge, UK)[24]. The ISP consisted of four quarters of 15 min, interspersed with 2 min passive rest after the first and third quarter and 5 min after the second (Fig. 1). The duration of the quarters in the present study were chosen to account for the fact that it has been shown that players remain active during stoppages[24]. Each quarter consisted of alternation between 20%, 50%, 60% and 75% of maximum speed separated with 10 s maximum effort sprints (9 x 10 s sprints per quarter), with 80% of the ISP conducted at ≤60% of maximum speed. During the last 2 min of each quarter, 4 x 15 s maximum effort sprints were performed, interspersed with 15 s passive rest. Percentage change in peak speed from the first to the last of these final 4 sprints was calculated ((last sprint speed- first sprint speed) / first speed *100)) to compare sprinting ability between quarters and across conditions. The protocol was terminated if participants reached the safety limit of high T_{gi} (39.5ºC).

The three conditions consisted of no cooling (NC), pre-cooling using an ice vest (P, Artic Heat Products, Burleigh Heads, Queensland, Australia) or the combination of pre-cooling and water spraying during the passive rest between quarters (PW). Pre-cooling was provided during the 15 min rest and 20 min warm-up. During the warm-up and the ISP, a fan positioned 1 m away from the participant was set at ~1.4 $m \cdot s^{-1}$ to mimic movement induced air flow during on-court match-play.

During the intermittent sprint protocol (ISP) participants wore their usual training attire of lightweight tracksuit trousers and a playing vest. For the pre-cooling conditions, the ice vest was frozen overnight at -20°C, weighed ~ 800g when activated and was worn over the top of the playing vest. The ice vest was made of SportWool™, Microfiber and pockets of viscose gel that absorb water. In PW, participants were also sprayed on the face, fronts of both arms and torso for a total of 20 s with a water spray (~50 ml per 20 s spray at 17°C), administered by the same researcher.

Seven iButtons (DS1922T, Maxim Integrated Products, Inc., Sunnyvale, CA, USA) were placed on the forehead and right side of the body on the forearm, upper arm , upper back, chest, abdomen, thigh and calf. In addition to individual skin temperatures, T_{sk} was estimated using the formula by Ramanathan [25].

Heart rate (HR, Polar PE 4000, Kempele Finland) was recorded throughout the ISP. Thermal comfort and thermal sensation were recorded at the start and end of the 15 min rest, warm-up and each quarter. The thermal sensation scale, comprised of categories ranging from 0 ("unbearably cold") to 8 ("unbearably hot") in 0.5 increments [26]. The thermal comfort scale ranged from 1 ("comfortable") to 4 ("very uncomfortable") in 1.0 increments [27].

Participants were allowed to drink *ad libitum* during breaks between quarters and the volume of fluid was recorded. Participants were re-weighed at the end of the ISP. In addition to the absolute change in body mass ($Mass_{pre}$ - $Mass_{post}$), the change in body mass in relation to fluid consumed (($Mass_{pre}$ - $Mass_{post}$) + fluid consumed) was also calculated (total mass loss).

All data were analysed using the Statistical Package for Social Sciences (version 19; SPSS Chicago, IL). The change in T_{gi}, T_{sk} and individual skin temperatures were calculated as the change from the start of the 15 min rest period. Analysis of the aforementioned parameters was performed separately for the 15 min rest period and the total pre-cooling period (combination of the 15 min rest period and the 20 min warm-up) (Figure 1). Normality of data was confirmed by the Shapiro–Wilk test. One participant was stopped during two of the three trials due to T_{gi} reaching the safety limit of 39.5°C. Subsequently, temperature estimations for three missing data points (out of a total of 264) for this participant were performed by substitution of the mean temperature change, enabling the thermoregulatory responses to be presented from all eight participants. The analysis for the sprint performance data was conducted with n = 7, due to missing data for one quarter.

Physiological responses, thermoregulatory responses and sprint performance were analysed using a two way (condition x time) analysis of variance. Where assumptions of sphericity were violated, a Greenhouse–Geisser correction was applied. Post hoc analysis was conducted using pairwise comparisons with a Bonferroni correction. Main effects and interactions were accepted as statistically significant when $P<0.05$. All values are presented as mean ± SD. Mean differences, 95% confidence intervals (CI) and effect sizes (ES) were calculated, to supplement important findings, as the ratio of the mean difference to the pooled SD of the difference. The magnitude of the ES was classed as trivial (<0.2), small (0.2–0.6), moderate (0.6–1.2), large (1.2–2.0) and very large (⩾2.0) based on previous guidelines [28].

Results

T_{gi} at baseline (36.8 ± 0.1°C, 36.7 ± 0.5°C and 37.1 ± 0.3°C for NC, P and PW, respectively, P=0.06) and the change in T_{gi} during the rest and pre-cooling period were not significantly different between conditions (P>0.05). The change in T_{gi} during the ISP was significantly smaller from the end of quarter 2 to the end of quarter 4 in PW and P compared to NC (P<0.05, Fig. 2). At the end of quarter 4, change in T_{gi} in PW (1.3 ± 0.9ºC) was significantly smaller than both NC (1.9 ± 0.7 ºC, P<0.01, ES=0.7) and P (1.7 ± 0.8ºC, P<0.001, ES=0.5). The rate of T_{gi} increase over the ISP was smaller in

PW (0.015 ± 0.007ºC·min^{-1}, P<0.01) than NC (0.021 ± 0.008ºC·min^{-1}, P=0.01, ES = 0.8) and P (0.020 ± 0.008ºC·min^{-1}, P=0.05, ES=0.7).

T_{sk} at baseline was not significantly different between conditions (30.9 ± 0.5 °C, 31.1 ± 1.1°C and 30.8 ± 0.8°C for NC, P and PW, respectively, P=0.58). The change in T_{sk} was significantly greater in P and PW compared to NC at the end of the rest (mean difference = -1.3, 95% CI = -1.8 to -0.8, ES = 2.8, P=0.004 and mean difference = -1.3, 95% CI = -2.0 to -0.6, ES=2.0, P=0.04 for P and PW, respectively) and pre-cooling period (mean difference = -0.8, 95% CI = -1.5 to 0.0, ES=1.1, P=0.03 and mean difference = -0.5, 95% CI = -1.0 to 0.1, ES = 0.8, P=0.05 for P and PW, respectively). At the start and end of the first quarter the change in T_{sk} was smaller in P than NC (P<0.05), though neither were significantly different to PW. By the end of quarter 2 to the end of quarter 4, the change in T_{sk} was smaller in PW compared to P and NC (P<0.05, Fig. 2). At the end of quarter 4, the change in T_{sk} from the start of the rest period revealed a large ES and was significantly smaller in PW (-2.33 ± 0.77°C) compared to NC (-0.59 ± 0.72°C, P<0.001, ES=2.3) and P (-0.65 ± 0.69°C, P=0.01, ES=2.3).

For individual skin temperatures, only the change in chest and abdomen skin temperatures were significantly greater in P and PW than NC during the pre-cooling period (P<0.001). The change in skin temperature at the upper arm (0.76 ± 0.86 and -1.34 ± 2.26ºC for NC and PW, respectively), chest (-0.36 ± 1.18 and -1.74 ± 1.85ºC for NC and PW, respectively), forearm (1.28 ± 1.02ºC and -0.44 ± 1.39ºC for NC and PW, respectively), forehead (-0.36 ± 1.66ºC and -3.06 ± 2.57ºC for NC and PW, respectively) and abdomen (1.24 ± 1.71ºC and -0.03 ± 2.02ºC for NC and PW, respectively) were all smaller in PW than in NC during the ISP (P<0.05). The change in chest (-0.44 ± 1.57 for P and PW, respectively), forearm (1.15 ± 0.93ºC and -0.72 ± 1.44ºC for P and PW, respectively) and upper arm (0.76 ± 0.87ºC and -1.87 ± 2.36ºC for P and PW, respectively) were also smaller in PW than P from the start of quarter 2 to the end of quarter 4 (P<0.05). There were no differences between NC and P for the change in any of the individual skin temperatures.

Pre-cooling had no effect on HR, RPE, thermal sensation or thermal comfort (P>0.05). Heart rate, RPE, thermal sensation and thermal comfort were similar between conditions during the ISP (P>0.05,

Table 1). A greater percentage of body mass was gained in NC than PW (P=0.03, ES=1.3) due to significantly more fluid being consumed in NC than in PW (P<0.03, ES=0.9), whilst fluid consumption in P was not different to the other two conditions (P=0.12, ES=0.3 and P=0.49, ES=0.5 compared to NC and P, respectively). Taking into account fluid intake, there were no significant differences and small ES between conditions for total mass loss (P=0.49, ES=0.1-0.4, Table 1).

Despite the condition, participants reached similar peak speeds during the three maximum effort 15 s sprints at the end of the warm-up, thus, participant's speed zones for each condition were not significantly different (P=0.25, ES=0.1). No differences were observed between the conditions or over time for peak and mean speed, mean and peak power, total distance covered and total work done during the quarters (all P>0.11). Participants performed intermittent sprints during each quarter and then completed four final 15 s sprints at the end of each quarter. The performance data for the latter 4 sprints averaged across each condition are shown in Table 1. For the four end of quarter sprints, no difference between conditions or over time for peak speed, peak and mean power, time to peak speed and percentage change in peak speed were apparent (all P>0.37). There was no effect of trial order on performance variables (P=0.51).

Insert Table 1 here

Discussion

The present study demonstrated that the combined methods of pre-cooling using an ice vest and water spraying (PW) between quarters attenuated thermal strain to a greater degree than solely employing a pre-cooling ice vest strategy (P) during simulated WCR match-play, partially accepting the hypothesis. Pre-cooling only (P) reduced the change in T_{gi} throughout the second half of the ISP compared to NC, providing a smaller, compared to PW, but still substantial attenuation of T_{gi}. Yet, the greater negative change in T_{sk} from pre-cooling in P, compared to NC, was not long lasting during the ISP. Interestingly, despite employing a protocol based on the activity profiles of WCR match-play, neither cooling condition had an effect on performance.

The ice vest's application during a 20 min rest period in previous studies showed similar reductions in T_{gi} (-0.3ºC) and T_{sk} (-1.7ºC) [10,14]. However, former studies have often overlooked the importance and influence that a warm-up has on the thermoregulatory responses of athletes [10,14]. In the present study the strategy of pre-cooling during rest followed by a 20 min warm-up reflects the "real-world" preparation for matches, lowering T_{gi}, on average, by only 0.1ºC by the end of the pre-cooling period compared to NC. Thus, future studies should include a warm-up to ensure ecological validity of the protocol.

Although no cooling was applied during the ISP, the offset of T_{gi} from pre-cooling led to a smaller change in T_{gi} throughout in P compared to NC. Cooling the skin surface with the ice vest lowered peripheral tissue heat content sufficiently to act as a heat sink, enabling the blood returning to the central circulation from the periphery to be cooled [29]. Thus resulting in a lower heat accumulation in the body core during the ISP, even though the drop in T_{sk} was not long lasting. With the addition of the water sprays between quarters in PW, a further attenuated T_{gi} throughout the second half of the ISP compared to NC, and by the end of the ISP compared to P was noted. The water sprays in PW, that covered the majority of the anterior torso, cooled the skin's surface, resulting in a lower T_{sk} response throughout the second portion of the ISP compared to P and NC. One might expect water spraying the face, torso and arms to impact thermal perceptions in line with the attenuation of T_{gi} and T_{sk}. Yet, the athletes did not perceive to be any cooler in either P or PW compared to NC. Therefore, due to only a small portion of their skin being sensate, the reporting of thermal perceptions may be limited to a small surface area in SCI [30].

The combination of cooling methods (PW) may have influenced the amount of fluid ingested because compared to NC a smaller amount of fluid was consumed. In NC the greater amount of fluid consumed, coupled with an absence or minimal sweating, resulted in a greater gain in body mass, akin to previous research.[31] Although significant differences in fluid consumption occurred between NC and PW, due to the individual's sweating dysfunction a significant difference between conditions in total mass loss was not apparent. Thus, the use of cooling strategies in this population group in the ambient conditions studied does not seem to have a detrimental effect on fluid ingestion, in contrast to previous research in the heat [13]. In addition the results highlight that due to only a small gain in body mass (<1.5%) in all three conditions, participants were able to effectively replace their small fluid losses. Thus the participant's *ad libitum* fluid consumption avoided a detrimental effect on performance and the risk of over drinking, which would have resulted in frequent voids and the increased risk of autonomic dysreflexia.[32]

Performance variables measured either during each quarter or end of quarter sprints were similar between conditions, which is in contrast to Webborn et al. [10]. Furthermore, the lack of differences in performance variables and percentage change in end of quarter sprints may indicate that substantial fatigue was not generated or participants were pacing their effort over the four sprints. This is consistent with indoor tracking data which has shown that activity profiles of elite WCR players do not significantly deviate across full matches [24], suggesting match-play activity is not influenced by fatigue. Whether a difference in actual match-play performance would have been found following similar cooling techniques is however unknown.

Conclusion

In conclusion, the present study aimed to determine the effectiveness of cooling methods currently used by athletes with tetraplegia on simulated WCR match-play. Pre-cooling using an ice vest resulted in a greater reduction in T_{sk} during the pre-cooling period and although this response was not long lasting, the change in T_{gi} was still lower in P compared to NC throughout the ISP. Even though neither cooling condition had a positive nor a detrimental effect on performance or perceptual responses, the combination of methods in PW both lowered T_{gi} compared to NC and lowered T_{sk} compared to both NC and P during the ISP.

Practical implications

1. Pre-cooling using an ice vest during an initial 15 min rest period and 20 min warm-up attenuated the rise in gastrointestinal temperature, whilst the addition of water sprays provided further reductions in thermal strain.
2. Athletes with tetraplegia should employ the combination of pre-cooling using an ice vest and water sprays between quarters to lower thermal strain to a greater degree than solely employing a pre-cooling ice vest strategy.
3. Despite lowering thermal strain by employing the combination of methods and attenuating the rise in gastrointestinal temperature in the pre-cooling only condition, neither cooling condition had a positive nor a detrimental effect on performance or perceptual responses.

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References

1. Hopman MT. Circulatory responses during arm exercise in individuals with paraplegia. *Int J Sports Med* 1994; 15(3):126-131.

2. Normell LA. Distribution of impaired cutaneous vasomotor and sudomotor function in paraplegic man. *Scand J Clin Lab Invest Suppl* 1974; 138:25-41.

3. Price MJ, Campbell IG. Effects of spinal cord lesion level upon thermoregulation during exercise in the heat. *Med Sci Sports Exerc* 2003; 35(7):1100-1107.

4. Griggs KE, Leicht CA, Price MJ, et al. Thermoregulation during intermittent exercise in athletes with a spinal-cord injury. *Int J Sports Physiol Perform* 2015; 10(4):469-475.

5. Tyler CJ, Sunderland C, Cheung SS. The effect of cooling prior to and during exercise on exercise performance and capacity in the heat: a meta-analysis. *Br J Sports Med* 2015; 49(1):7-13.

6. Quod MJ, Martin DT, Laursen PB. Cooling athletes before competition in the heat: comparison of techniques and practical considerations. *Sports Med* 2006; 36(8):671-682.

7. Ross M, Abbiss C, Laursen P, et al. Precooling methods and their effects on athletic performance : a systematic review and practical applications. *Sports Med* 2013; 43(3):207-225.

8. Wegmann M, Faude O, Poppendieck W, et al. Pre-cooling and sports performance: a meta-analytical review. *Sports Med* 2012; 42(7):545-564.

9. Bongers CC, Thijssen DH, Veltmeijer MT, et al. Precooling and percooling (cooling during exercise) both improve performance in the heat: a meta-analytical review. *Br J Sports Med* 2014; 96(5):650-658.

10. Webborn N, Price MJ, Castle P, et al. Cooling strategies improve intermittent sprint performance in the heat of athletes with tetraplegia. *Br J Sports Med* 2010; 44(6):455-460.

11. Diaper NJ, Goosey-Tolfrey V. A physiological case study of a paralympic wheelchair tennis player: reflective practise. *J Sports Sci Med* 2009; 8(2):300-307.

12. Goosey-Tolfrey V, Swainson M, Boyd C, et al. The effectiveness of hand cooling at reducing exercise-induced hyperthermia and improving distance-race performance in wheelchair and able-bodied athletes. *J Appl Physiol* 2008; 105(1):37-43.

13. Goosey-Tolfrey VL, Diaper NJ, Crosland J, et al. Fluid Intake During Wheelchair Exercise in the Heat: Effects of Localized Cooling Garments. *Int J Sports Physiol Perform* 2008; 3(2):145-156.

14. Webborn N, Price MJ, Castle PC, et al. Effects of two cooling strategies on thermoregulatory responses of tetraplegic athletes during repeated intermittent exercise in the heat. *J Appl Physiol* 2005; 98(6):2101-2107.

15. Hagobian TA, Jacobs KA, Kiratli BJ, et al. Foot cooling reduces exercise-induced hyperthermia in men with spinal cord injury. *Med Sci Sports Exerc* 2004; 36(3):411-417.

16. Bongers CC, Eijsvogels TM, van Nes IJ, et al. Effects of Cooling During Exercise on Thermoregulatory Responses of Men With Paraplegia. *Phys Ther* 2016; 96(5):650-658.

17. Pritchett RC, Bishop PA, Yang Z, et al. Evaluation of artificial sweat in athletes with spinal cord injuries. *Eur J Appl Physiol* 2010; 109(1):125-131.

18. Trbovich M, Ortega C, Schroeder J, et al. Effect of a cooling vest on core temperature in athletes with and without spinal cord injury. *Topics in spinal cord injury rehabilitation* 2014; 20(1):70-80.

19. Armstrong LEL, Maresh CMC, Riebe DD, et al. Local cooling in wheelchair athletes during exercise-heat stress. *Med Sci Sports Exerc* 1995; 27(2):211-216.

20. Forsyth P, Pumpa K, Knight E, Miller J. Physiological and perceptual effects of precooling in wheelchair basketball athletes. *J Spinal Cord Med* 2016; 39(6):671-678.

21. Griggs KE, Price MJ, Goosey-Tolfrey VL. Cooling Athletes with a Spinal Cord Injury. *Sports Med* 2015; 45:9-21.

22. Price MJ, Campbell IG. Thermoregulatory and physiological responses of wheelchair athletes to prolonged arm crank and wheelchair exercise. *Int J Sports Med* 1999; 20(7):457-463.

23. Leicht CA, Griggs KE, Lavin J, et al. Blood lactate and ventilatory thresholds in wheelchair athletes with tetraplegia and paraplegia. *Eur J Appl Physiol* 2014; 114(8):1635-1643.

24. Rhodes JM, Mason BS, Perrat B, et al. Activity profiles of elite wheelchair rugby players during competition. *Int J Sports Physiol Perform* 2015; 10(3):318-324.

25.Ramanathan NL. A New Weighting System for Mean Surface Temperature of the Human Body. *J Appl Physiol* 1964; 19:531-533.

26. Toner MM, Drolet LL, Pandolf KB. Perceptual and physiological responses during exercise in cool and cold water. *Percept Mot Skills* 1986; 62(1):211-220.

27. Gagge AP, Stolwijk JA, Saltin B. Comfort and thermal sensations and associated physiological responses during exercise at various ambient temperatures. *Environ Res* 1969; 2(3):209-229.

28. Batterham AM, Hopkins WG. Making Meaningful Inferences About Magnitudes. *Int J Sport Physiol Perform* 2006; 1(1):50-57.

29. Webb, P. Afterdrop of body temperature during rewarming: an alternative explanation. *J Appl Physiol* 1986; 60(2):385-390.

30. Attia M, Engel P. Thermoregulatory set point in patients with spinal cord injuries (spinal man). *Paraplegia* 1983; 21(4):233-248.

31. Black KE, Huxford J, Perry T, et al. Fluid and sodium balance of elite wheelchair rugby players. *Int J Sport Nutr Exerc Metab* 2013; 23(2):110-118.

32. Krassioukov A, Claydon.VE. The clinical problems in cardiovascular control following spinal cord injury: An overview. *Prog. Brain Res* 2006; 152:223–229.

Fig. 1. Schematic of protocol, including when cooling was applied in each condition. The white box depicts the warm-up, the grey boxes the intermittent sprint protocol (ISP) and the dotted grey boxes the 15 s sprints. ISP = intermittent sprint protocol, B= break, NC = no cooling, P = pre-cooling using an ice vest, PW = pre-cooling using an ice vest and water sprays during breaks.

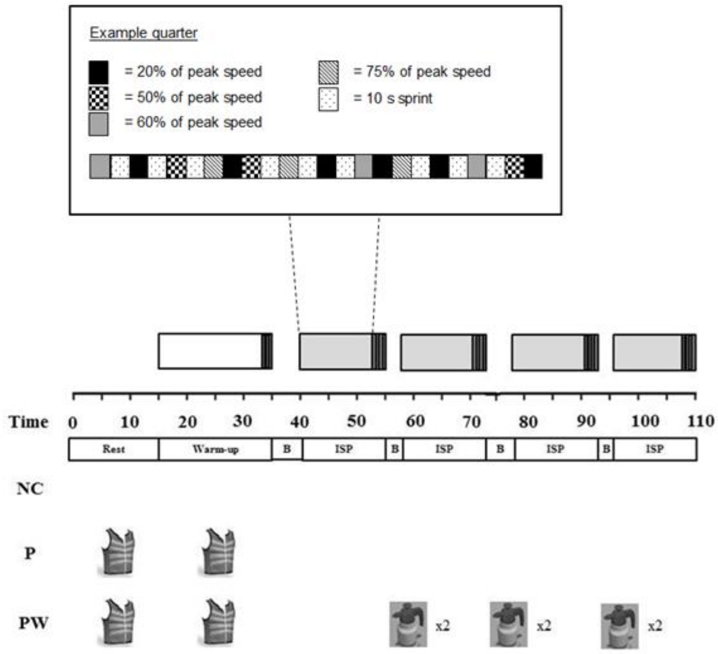

Fig. 2. Change in (A) gastrointestinal temperature and (B) mean skin temperature over the pre-cooling period and the intermittent sprint protocol for the three conditions; no cooling (NC), pre-cooling using an ice vest (P) and pre-cooling using an ice vest and water sprays between quarters (PW). (a) significant difference between NC and P, P<0.05. (b) significant difference between NC and PW, P<0.05. (c) significant difference between P and PW, P<0.05. Note: the change in gastrointestinal and mean skin temperature was calculated as the change from the start of the 15 min rest period.

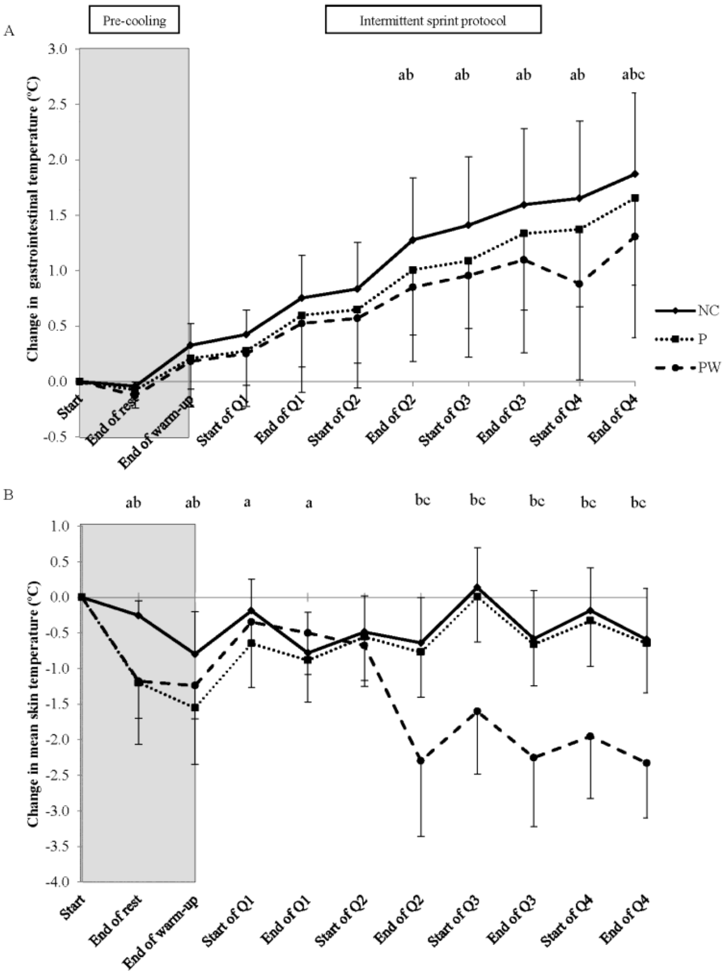

Table 1 Performance data for the four end of quarter sprints averaged across each condition and mean heart rate, perceptual responses and fluid balance for each condition.

		NC	P	PW
Mean performance data for the four end of quarter sprints	Peak speed (m·s^{-1})	4.11 ± 0.66	4.08 ± 0.77	4.08 ± 0.71
	Peak power (W)	380 ± 168	366 ± 157	386 ± 184
	Mean power (W)	274 ± 145	263 ± 135	278 ± 155
	Time to peak speed (s)	7.9 ± 3.0	7.5 ± 2.6	7.4 ± 2.4
	Change in peak speed (%)	-5.89 ± 5.67	-5.54 ± 6.99	4.61 ± 7.15
Heart rate, perceptual responses and fluid balance averaged over the whole condition	Heart rate (b·min^{-1})	96 ± 21	91 ± 23	94 ± 23
	Rating of perceived exertion	17 ± 2	16 ± 2	16 ± 2
	Thermal sensation	5.0 ± 1.0	5.0 ± 1.0	5.0 ± 1.0
	Thermal comfort	2.0 ± 1.0	2.0 ± 1.0	2.0 ± 1.0
	Absolute body mass loss (kg)	-0.9 ± 0.2	-0.6 ± 0.3	-0.5 ± 0.4*
	Body mass loss (%)	-1.4 ± 0.3	-1.0 ± 0.5	-0.8 ± 0.6*
	Fluid consumption (ml)	819 ± 250	674 ± 285	596 ± 250*
	Total mass loss (kg)	0.0 ± 0.3	0.1 ± 0.3	0.1 ± 0.2

*significantly different to NC ($P<0.05$)