Cooling Athletes with a Spinal Cord Injury

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Short title/ Running head

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Key Points

- According to the studies reviewed, wearing an ice vest during intermittent sprint exercise both reduces thermal strain and enhances performance.
- A combination of pre-cooling and cooling during exercise or half-time cooling may be an effective strategy.
- Cooling strategies for athletes with a spinal cord injury should be individualized to account for the level and completeness of the lesion while also considering the specific regulations and logistics of the sport involved.

Abstract

Cooling strategies that help prevent a reduction in exercise capacity whilst exercising in the heat have received considerable research interest over the past three decades, especially in the lead up to a relatively hot Olympic and Paralympic Games. Progressing into the next Olympic/Paralympic cycle the host, Rio de Janeiro, could again present an environmental challenge for those athletes competing. Despite the interest and vast array of research into cooling strategies for the able-bodied athlete, less is known regarding the application of these cooling strategies in the thermoregulatory impaired spinal cord injured (SCI) athletic population. Individuals with a spinal cord injury (SCI) have a reduced afferent input to the thermoregulatory centre and a loss of both sweating capacity and vasomotor control below the level of the spinal cord lesion. The magnitude of this thermoregulatory impairment is proportional to the level of the lesion. For instance, individuals with high level lesions (tetraplegia) are at a greater risk of heat illness than individuals with lower level lesions (paraplegia) at a given exercise intensity. Therefore, cooling strategies may be highly beneficial in this population group, even in moderate ambient conditions (~21°C). This review was undertaken to examine the scientific literature that addresses the application of cooling strategies in individuals with a SCI. Each method is discussed in regards to the practical issues associated with the method and the potential underlying mechanism. For instance, site specific cooling would be more suitable for an athlete with a SCI than whole body water immersion, due to the practical difficulties of administering this method in this population group. From the studies reviewed, wearing an ice vest during intermittent sprint exercise has been shown to decrease thermal strain and improve performance. These garments have also been shown to be effective during exercise in the able-bodied. Drawing on additional findings from the able-bodied literature the combination of methods used prior to and during exercise and/or during rest periods/half-time may increase the effectiveness of a strategy. However, due to the paucity of research involving athletes with a SCI, it is difficult to establish an optimal cooling strategy. Future studies are needed to ensure that research outcomes can be translated into meaningful performance enhancements by investigating cooling strategies under the constraints of actual competition. Cooling strategies which meet the demands of intermittent wheelchair sports need to be identified, with particular attention to the logistics of the sport.

1 Introduction

Prolonged exercise in high ambient temperatures and/or high humidity has a detrimental effect on physical performance in able-bodied individuals.[1] Cooling strategies that reduce the attenuation of athletic performance have been investigated over the past three decades. There has been increasing interest in cooling strategies, particularly in the lead up to a relatively hot Olympic Games, such as Athens 2004 (30-38°C, 40-48% relative humidity)[2] or Beijing 2008 (20-30°C, 63-90% relative humidity).[3] Progressing into the next Olympic/Paralympic cycle, the Rio de Janeiro 2016 Games will again present a unique challenge for the athlete, with the need to prepare and adapt to the potential environmental conditions of 19-29°C and ~70% relative humidity.[4]

Despite the interest in the application of cooling strategies for the able-bodied athlete, comparatively little is known regarding this for a wheelchair bound athletic population, specifically athletes with a spinal cord injury (SCI). Individuals with a SCI have a reduced afferent input to the thermoregulatory centre[5-7] and a loss of both sweating capacity and vasomotor control below the level of the spinal cord lesion.[5, 8, 9]As blood redistribution and sweating are two major thermoregulatory effectors, this suggests that individuals with a SCI have compromised thermoregulation and a greater risk of heat illness than able-bodied individuals.[10]

The magnitude of the thermoregulatory impairment is proportional to the level and completeness of the lesion. For instance, exercising for 60-90 minutes at 60% peak oxygen uptake ($\dot{V}O_{2peak}$) in 15-25°C, athletes with a thoracic, lumbar or sacral SCI (paraplegia) may experience an increase in core temperature (T_{core}) of ~1°C, similar to their able-bodied counterparts.[11, 12] For the same exercise intensity in hot conditions (35-40°C), a greater increase in T_{core} over time may be apparent, when compared to the able-bodied, signifying an imbalance between heat loss and heat gain, though exercise can still be maintained.[13] Above exercise intensities of 60% $\dot{V}O_{2peak}$ in hot conditions, sweating and heat production may become unbalanced causing an increased risk of heat injury for athletes with paraplegia.[10] Compared to individuals with paraplegia or an incomplete spinal injury, individuals with a cervical SCI (tetraplegia) and/or a complete injury possess a smaller area of sensate skin, a lesser amount of afferent input regarding their thermal state and a reduced efferent response.[9, 14] Limited data is available for athletes with tetraplegia regarding heat strain in relation to exercise intensity, yet their high level lesions predispose them to a greater degree of thermal strain than athletes with paraplegia.[11, 15]

In an athletic setting, it is imperative that the appropriate training practices, including cooling strategies, are applied to support athletic performance for athletes, but more importantly for those with a SCI, that the risk of heat injury is also considered. The purpose of this review is to examine the scientific literature addressing application of cooling strategies to individuals with a SCI with specific reference to the practical and logistical issues associated with each method.[8] The potential underlying mechanism for improved heat tolerance for each method will also be addressed.

1.1 Methods

A comprehensive literature search was conducted using the search engines Web of Science, SPORTDiscus, MEDLINE and Biological Sciences. Key terms employed included “cooling,” with “sport,” “Paralympic,” “wheelchair sport,” “exercise,” “performance,” with “spinal cord lesion,” “spinal cord injury,” “tetraplegia,” “quadriplegia” and “paraplegia.” The last day of the literature search was 09 May 2014. The inclusion criteria comprised studies that reported a population group of individuals with a SCI, use of cooling strategies with exercise and articles that were published in English language peer reviewed journals. Figure 1 provides a flow diagram of the literature search. By assessing the eligibility of the articles, in regards to the inclusion criteria, nine articles were selected for review (Table 1).

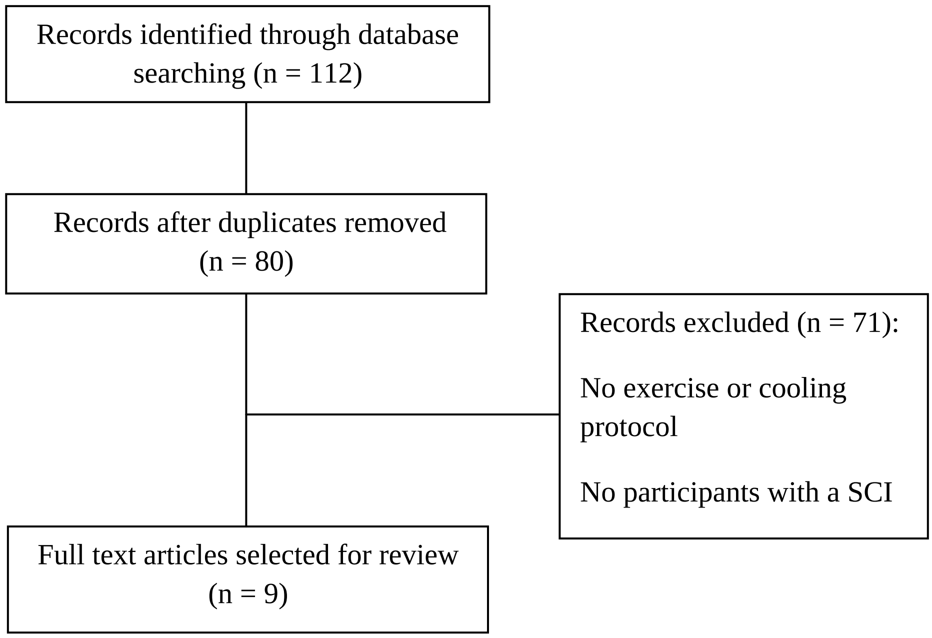

Figure 1. Overview of study selection process. n indicates number of studies. SCI spinal cord injury.

Insert Table 1 here

2 Cooling Methods

The majority of exercise-related cooling methods are applied externally, either in isolation or as a combination of methods. Recent studies have considered internal application by ingestion of a cooling medium (i.e. ice slurry).[16, 17] Widespread use of various cooling methods and techniques in research in the able-bodied population include; cold air exposure,[18, 19] wearing of ice vests,[20-22] whole body water immersion,[23-25] water immersion of the extremities[26, 27] and ice slurry or cold water ingestion.[16, 17] These methods influence the body in different ways by either reducing T_{core} and mean skin temperature (T_{sk}) (water immersion); reducing T_{core} with no effect on T_{sk} (ice slurry or cold water ingestion) or primarily reducing T_{sk} (ice vests, cold air exposure, water sprays). Methods differ greatly in terms of their physiological effects, cooling power and, importantly, the timing of application. Moreover, the duration of the cooling strategy employed is also crucial to ensure maximum benefit to the athlete's performance without compromising athlete comfort or pre-event/half-time routine. Depending on the method used, the time required to achieve a significant reduction in T_{core} has been shown to range from 15-60 minutes of cooling.[28, 29] In assessing the practicality of a cooling method for an athletic population the effectiveness, sporting regulations, staffing/assistance, logistics, cost and athlete comfort need to be considered. Although, there is still debate regarding which strategy provides the greatest performance benefit in the able-bodied population, recent meta-analysis data has shown that pre-cooling, especially mixed method cooling,[30] can improve subsequent intermittent and prolonged exercise performance in the heat.[31] During exercise, meta-analysis data has revealed the use of ice vests to have the largest effect on performance.[30]

Insert Table 2 here

2.1 Hand/Foot cooling

An alternative to whole body water immersion is to submerge, in water, inactive or active body parts. An advantage of water immersion, even if only partial immersion, is that the thermal conductivity of water is 27 times greater than the thermal conductivity of air at the same temperature, causing greater heat loss in water compared to air.[32] For instance, cooling of the hands or feet for 20 minutes in 10°C water has been shown to remove heat of 100-150 W.[33, 34] Consequently, a reduction in T_{sk} and possibly T_{core}, can be achieved without directly cooling active muscle tissue enabling greater potential for heat storage.[35] Compared to the practically difficult method of whole body water immersion, this site-specific cooling, in particular cooling of the extremities, is more accessible for athletes with a SCI. Furthermore, cooling of the extremities in water is a self-limiting method of cooling, whereby the peripheral blood flow controls the degree of cooling which is in turn driven by the level of T_{core}.[27] This method of cooling thus relies on an elevated T_{core} in order for the cooler venous blood in the hands and feet to flow directly to the core through the superficial veins.[27, 33, 34] Without this drive for blood flow, vasoconstriction occurs and heat loss is prevented[27] and further elevations in heat storage will occur.

To assess if cooling hyperthermic athletes with a SCI following 60 minutes of steady state exercise in ~31°C improved subsequent 1 km time trial performance, Goosey-Tolfrey et al.[36] demonstrated that immersing the hands in 10°C water for 10 minutes elicited a 0.4°C reduction in insulated aural temperature (T_{ac}). Time to complete 1 km was improved by 20.5 seconds, yet this was non-significant. A statistically significant performance improvement may have been masked by the diverse range of disabilities examined within this study (Table 1), which included both athletes with tetraplegia and paraplegia. During exercise, substantial thermoregulatory differences have been observed between high (tetraplegia) and low (paraplegia) lesion levels, indicating that the thermal responses, and as a consequence, performance, of athletes with paraplegia and tetraplegia in this study may have been different.[11] As the chosen performance trial is not a standard race distance for wheelchair athletes whether this small reduction in performance has practical significance in a competition setting has yet to be determined.

In comparison to the able-bodied control group, the athletes with a SCI in the study by Goosey-Tolfrey et al.[36] experienced a smaller increase in T_{ac} from the steady state exercise (2.0°C vs 1.3°C for the able-bodied and wheelchair athletes, respectively) and a smaller reduction in T_{ac}

from cooling the hands, due to the lower thermal drive for cutaneous blood flow and thus cooling. The authors also noted that although thermal sensation was slightly reduced following hand cooling, the wheelchair athletes experienced a lack of grip and feelings of numbness of the hands, indicating that immersing the hands for 10 minutes in 10°C water may not be appropriate for wheelchair court sports where hand dexterity is of paramount importance. Many athletes in wheelchair sports wear gloves making hand cooling before or during play practically difficult. Consequently, cooling inactive body regions, such as the feet, may be more suitable, to ensure upper body movement and hand dexterity needed for wheelchair propulsion are not inhibited.

Cooling devices which target the heat-exchanging arteriovenous anastomoses in the feet have been developed.[37] Such devices increase the transfer of heat by alternating between negative and neutral pressure to facilitate blood return from the lower extremities and apply a heat sink to the skin surface, increasing the extraction of heat from the circulating blood.[37] One of these foot cooling devices was used by Hagobian et al.[37] to cool individuals with a SCI during 45 minutes of arm cranking at 66% $\dot{V}O_{2peak}$ in 32°C conditions. The increase in tympanic temperature (T_{ty}) was attenuated by 0.6°C in the foot cooling condition (1.0°C vs. 1.6°C, respectively). It should be noted that T_{ty} was not attenuated when negative pressure was not applied, potentially due to a reduction in cutaneous blood flow in the feet. However, the thermal responses of the participants in Hagobian et al.[37] may have been accentuated as participants were untrained (arm crank $\dot{V}O_{2peak}$ 14.4 ± 2.9 $ml \cdot kg^{-1} \cdot min^{-1}$). Therefore, they may have experienced a lower dissipation of heat and greater increases in T_{core} compared to trained individuals,[10] who could potentially benefit from partial acclimation.[38] Similarly to Goosey-Tolfrey et al.[36] the authors did not specify the number of participants with tetraplegia or paraplegia. Due to the lack of a performance measure used in this study, the effect on performance and practicality of using the device during competition is currently unknown. Future application of this method could investigate the use of this device post exercise or in a clinical setting.

2.2 Water Sprays

Players in wheelchair court sports with a SCI tend to use water sprays during rest periods to cool themselves due to their ease of use. The concept of using water sprays is to partially mimic the sweat response that an able-bodied individual would experience.[39] Despite this, only one study to date has investigated the use of water sprays in individuals with a SCI, in particular athletes with paraplegia. Pritchett et al.[39] conducted an incremental arm cranking protocol involving seven minute stages interspersed with 1 minute breaks when participants sprayed themselves *ad libitum*. The protocol was terminated voluntarily or when oesophageal temperature (T_{es}) rose by more than 0.2°C/min^{-1}. There were no differences between water spraying and no cooling in heart rate (HR), T_{es}, rectal temperature (T_{re}), T_{sk}, mean total work performed, rating of perceived exertion (RPE) or thermal sensation. Although the lack of positive findings may be due to the limited skin surface area covered by the water sprays (back of head, neck, forearm and face), due to the obstruction of clothing, this reflects the typical water spraying habits of wheelchair athletes. Interestingly, it has been suggested that a critical body surface cooling area of ~40% is needed to attenuate a rise in $T_{core,}$[40] though this is rarely achieved by cooling methods used by athletes. It is unknown which factor plays the greatest role in a cooling method's ability to dissipate heat; the amount of body surface area cooled or the specific body location.[41]

The absence of positive findings in the work of Pritchett et al.[39] may also be due to a number of limitations of the study. Although the authors stated that the protocol and ambient conditions (22°C, 45-50% relative humidity) were used to maintain high ecological validity, the exercise mode of arm cranking is not reflective of wheelchair court sports of an intermittent nature. Wheelchair propulsion has been shown to elicit lower physiological and thermal strain than arm cranking, potentially because the convective cooling currents generated by the arm action used to push the wheelchair increases the potential for peripheral heat loss.[42] Therefore, employing an exercise mode which does not reflect actual game play would consequently alter the ecological validity of the protocol. Secondly, players only experienced a slight increase in T_{core} by the end of the protocol (0.5°C). This could be because exercising at an air temperature (22°C) often classified as moderate,[43] trained individuals with paraplegia may be able to regulate heat loss similarly to an able-bodied counterpart in the absence of external heat gains.[10] As a high T_{core} is crucial for a cooling strategy to be effective, a more demanding exercise protocol, akin to a wheelchair basketball match, may have elicited a larger cooling improvement from water spraying. On this note, whether a similar outcome would be observed for players with tetraplegia is unknown.

Remarkably, Pritchett et al.[39] found no improvement in perceptual measures (thermal sensation and RPE) in the cooling condition. Evidence for the responsiveness of the face to cooling has shown a two to fivefold suppression of thermal discomfort in the face compared to cooling other body regions,[44] indicating that water spraying the face may be beneficial for thermal comfort. Although considered to be a practical method frequently used by many wheelchair athletes, caution is needed if thermal comfort is improved but there is no equivalent reduction in T_{core}, as athletes could potentially override signs of high levels of heat strain, putting them at risk of hyperthermia and heat illness.

2.3 Cooling Garments

Lightweight cooling garments have received considerable interest in the able-bodied athletic population.[20-22, 29, 45-47] An advantage of these garments is their potential use prior to or during exercise. However, a disadvantage is the trade-off between a lightweight garment with a sufficient cooling capacity, in relation to the amount and type of coolant contained in the garment. Recent developments in design features include; close-fitting designs, silica based gels to promote greater evaporative cooling, phase change materials that operate close to normal skin temperature[48] and wet cooling to increase heat transfer between torso and vest.[35] Cooling garments typically weigh ~1-4 kg;[28] bulkier cooling systems would be counter-active to the technology of the modern sports wheelchair, produced to reduce mass and improve aerodynamics.[49]

In the able-bodied athletic population, research into the use of cooling garments has predominantly focused on ice vests as a pre-cooling method prior to endurance exercise.[35] Pre-cooling using an ice vest, usually results in relative reductions in T_{sk}[29] and body temperature,[50] in addition to skin blood flow,[50] with no change in T_{core}.[50, 51] This suggests that the transfer of heat mainly occurs at the skin and less so at the core. The use of cooling garments prior to intermittent exercise has produced mixed results, being dependent upon the ambient condition, with positive effects found in warm environments (30-34°C).[52, 53] The use of ice vests as a pre-cooling method has been shown to improve performance by 4.8%[53] but also provide limited efficacy compared to ice slurry ingestion.[54] Yet, meta-analysis data has found wearing ice vests during exercise has a significantly larger effect (ES = 4.64) than other cooling techniques, such as cold water ingestion (ES = 1.75) and cooling packs (ES = 0.39).[30] Research into wearing these garments during sport is, however, still limited, due to sporting regulations and difficulty in incorporating such garments into athletic clothing worn during competition.

Although not as heavily researched, cooling devices for the head and neck, such as cooling hats, neckbands and headpieces, are also commercially available.[55-58] The rationale for garments that cool the head is based on the concept that this body region contains a high concentration of thermoreceptors,[59] as demonstrated by the head feeling warmer than the rest of the body in warm environments.[60] It should be noted, however, that the influence of head cooling and the extent to which brain temperature increases during exercise in the heat is unknown and needs to be further investigated.[61, 62] The neck area is a region of high thermosensitivity for both sudomotor and discomfort responses[44] yet few studies in the able-bodied have investigated cooling this region during exercise. The limited number of studies that have investigated the use of cooling neck collars have found a performance improvement whilst exercising in the heat (~30°C) and wearing the collars for 90 minutes during exercise (75 minutes at 60% $\dot{V}O_{2peak}$ followed by a 15 minute time trial).[57, 58] However, a shorter cooling exposure (during a 15 minute time trial) had no effect on time trial performance.[57] This suggests that the small surface area of cooling provided by the neck collars may only have an ergogenic effect under high levels of thermal strain and when worn for a long duration, below which a performance benefit cannot be achieved.[57]

In the athletic SCI population, the use of a refrigerated headpiece and an ice vest used to cool during 30 minutes of wheelchair exercise at 10 km race pace (~70% maximal aerobic power) has shown to provide no thermal, perceptual or performance benefit compared to no cooling.[49] The lack of a performance benefit observed may be due to the cooling potential of the two garments (75 W and 117 W for the headpiece and ice vest, respectively) being considerably lower than the metabolic heat generated during the exercise (704-766 W). From thermal manikin work, this commercially available vest has been found to extract only ~70 W of heat from the torso over 45 minutes at 26°C.[45] A greater cooling potential may have been achieved with additional ice packets in the vest covering a greater skin surface area.[49] However, this would increase the mass of the 3 kg garment, potentially hindering athletic performance. Practically, the length of time the ice vest stays cold also needs to be considered as once the ice strips of the vest have melted, cooling effectiveness is reduced. Therefore, applying this cooling method prior to exercise may be more practical and increase cooling effectiveness when compared to wearing the vest for a longer period of time during exercise.

Webborn et al.[63, 64] demonstrated promising results using ice vests prior to and during intermittent arm cranking exercise for athletes with tetraplegia. Twenty minutes of pre-cooling (PRE) and cooling during exercise (DUR) (warm-up and intermittent sprint protocol (ISP)) using an ice vest was shown to elicit lower T_{core} and thermal sensation throughout exercise, compared to no cooling. Despite T_{core} being greater in DUR throughout exercise, compared to PRE, a lower rate of increase resulted in similar T_{core} at the end of exercise. Pre-cooling demonstrated central cooling through an offset in the absolute increase in $T_{core.}$ Upon removal of the vest T_{sk} increased at a greater rate than the other conditions, due to the greater thermal gradient between the environment and the skin, but still remained lower than the no cooling condition. In contrast, in DUR, initial peripheral cooling may have been apparent as direct heat transfer from the body core to the periphery was facilitated, demonstrated by the lower rate of increase in T_{core} resulting in a cooling of the skin. Therefore, whether cooling before or during exercise is the most appropriate form of cooling may depend on whether peripheral or core cooling is of importance. In terms of sprint performance, whilst there were no differences in overall work done during the 14 sprint protocol,[63] the extended protocol of 30 sprints exhibited substantial differences between the conditions.[64] Athletes were able to complete more sprints in PRE and DUR than no cooling, with the greatest number of sprints completed in the latter. Peak power output significantly decreased in PRE (~15%) and the no cooling condition (~13%) over time, whilst this was not observed for DUR (~3%). The peak power output of the initial sprints in DUR were lower than the other conditions, which could be linked to the ability of the athletes to exercise for longer in DUR. Consequently, during the initial sprints the metabolic processes of the muscle will not have been stressed as greatly in DUR compared to the other two conditions, potentially allowing better recovery between sprints. This implies that cooling during exercise with an ice vest may not be ideal when the initial power output of sprints is essential to the overall performance. Participants also commented on the initial coldness of the vest, which may have affected their initial sprint performance from a psychological perspective.

To date, only one study has investigated the use of a cooling garment in a field based environment. Trbovich et al.[65] studied the use of a cooling vest containing phase change materials (reported to maintain at 15°C for 2-3 hours) during 60 minutes of wheelchair basketball or wheelchair rugby (21.1-23.9°C environmental temperature) in athletes with paraplegia and tetraplegia, respectively. A greater rise in T_{core} was experienced by the athletes with tetraplegia at the end of the 60 minutes compared to athletes with paraplegia, yet the cooling vest had no effect on T_{core} for either group. Even though this study may appear novel by exploring a cooling strategy in a field based environment for athletes with a SCI, a number of limitations are apparent which affects the application of the findings. Firstly, there was no control of or recording of exercise intensity. Secondly, although the sports are both of an intermittent nature using court sports wheelchairs, the kinematics of the sports differ,[66, 67] and a player's function and classification affects their speed and distance covered,[67] limiting the comparative nature of the study. Finally, irrespective of any thermal benefit, it is unclear if any performance benefit was provided by the cooling vest, or whether T_{sk} or perceptual responses were affected.

To ensure an athlete gets the most benefit from a cooling strategy, methods need to be practiced prior to major competitions to enable the athlete to elicit a coupling between the potential for heat storage and thermal sensation.[16] Diaper et al.[55] investigated pre-cooling using an ice vest and the combination of pre-cooling using an ice vest and cooling hats and neckbands during intermittent exercise (~30°C environmental temperature) for a wheelchair tennis player prior to a Paralympic Games. The player exhibited a lower T_{core}, thermal sensation and faster average peak speed using the combination of methods compared to pre-cooling only.[55] However, the study did not measure any other thermal or physiological parameters or provide a control condition to determine whether pre-cooling only had any thermal benefit compared to no cooling. The thermoregulatory and physiological effects of pre-cooling have been shown to wane after 30-40 minutes,[68, 69] therefore at the end of the 60 minute exercise protocol, the pre-cooling condition may have had limited benefit compared to no cooling. During a similar protocol and ambient conditions, Goosey-Tolfrey et al.[56] demonstrated the combined use of cooling hats and neckbands versus no cooling elicited lower RPE and thermal sensation during intermittent sprint exercise.[56] Although 42% less water was consumed during the cooling condition and sweat rates did not differ between conditions, athletes did maintain euhydration. Limited findings can be drawn in respect to the thermal benefit of this cooling strategy, as no thermal measures were taken, yet practically the cooling hats could be dual purpose (additional sun protection) during outdoor sports.

3 Timing of cooling application

3.1 Pre-cooling

Pre-cooling is based on the concept of starting exercise with a lowered body temperature to widen the temperature margin before reaching a critical limiting T_{core} contributing to fatigue.[70] It is generally accepted, in the able-bodied, that cooling prior to endurance and intermittent exercise elicits a performance improvement[31, 35, 53] (ES = 0.52 and ES = 0.43, respectively),[53] yet performance benefits are limited when cooling occurs prior to sprint exercise (ES = 0.03).[53] The extent of the performance improvement may also be dependent on the exercise duration, with the effect of pre-cooling decreasing for exercise durations over 60 minutes, potentially due to the limited duration of the cooling effect.[53] To enhance the cooling effect, a combination of methods could be used. Applying these methods simultaneously could also limit the time before an event that needs to be dedicated to pre-cooling.[35]

To maintain a physiological advantage and enhance performance pre-cooling needs to be provided as close to the start of exercise as possible and potentially during the warm-up.[20, 63] In light of this, previous cooling research in the able-bodied has sometimes failed to account for the effect of athletes' warm-up prior to competition thus limiting its application in a field environment. Nevertheless, pre-cooling during a warm-up will depend on the body area cooled and the method of cooling. A heavy cooling garment worn during the warm-up may also affect the metabolic cost of exercise, with the intensity of the warm-up needing to be adjusted accordingly.[20] Lastly, the cooling intensity of the strategy is particularly important as a sharp decrease in T_{core}, T_{sk} or muscle temperature prior to exercise may have a detrimental effect on performance.[53, 71, 72]

Two of the three studies reviewed utilising cooling with ice vests prior to intermittent sprint exercise observed a performance and thermal benefit compared to no cooling.[63, 64] A combination of pre-cooling using ice vests and cooling hats and neckbands during exercise, to attenuate the rise in T_{core} and thermal sensation, has also been shown to be effective as a case study.[55] Therefore, there may be some justification for pre-cooling using ice vests in athletes with a SCI, though further work is greatly needed.

3.2 Cooling during exercise/ rest periods

To offset the gains in heat throughout exercise, cooling during exercise has been utilised, predominantly through the use of ice vests. As previously mentioned, the difficulty with this cooling technique is to avoid an adverse effect on performance due to the size, coverage and weight of the cooling garment. Hence, due to this complexity, cooling during exercise has received less research attention than pre-cooling. Although research in the able-bodied shows that it could be just as effective as pre-cooling in improving performance.[30]

In addition to cooling during exercise, cooling provided during rest periods between multiple bouts of exercise could be viable for many team sports i.e. wheelchair courts sports. Strategies employed during these rest periods need to ensure minimal influence on athlete preparation. Due to the limited time athletes are allowed during rest periods/half-time (2-15 minutes depending on the wheelchair court sport) this may not allow for enough cooling exposure, but may provide some benefit compared to no cooling at all. Therefore, to enhance the cooling effect, a combination of both pre-cooling and cooling during rest periods/half-time may be more effective at reducing thermal strain by offsetting heat storage during the subsequent bout of exercise.[73]

Cooling during exercise was utilised in seven reviewed studies[37, 49, 55, 56, 63-65] with mixed results. Either performance was improved or T_{core} reduced when using ice vests, cooling hats and neckbands during intermittent exercise for trained wheelchair athletes.[55, 63, 64] Though, in a field based environment a cooling vest had no effect on T_{core} during a game of wheelchair basketball or wheelchair rugby.[65] During continuous exercise, foot cooling was thermally beneficial to untrained individuals, yet a refrigerated headpiece and ice vest provided no benefit to trained wheelchair athletes, due to the low cooling potential of the garments.[37, 49] In the two studies that applied cooling during rest periods, the use of water sprays had no thermal or performance effect whilst hand cooling provided more positive findings, though as previously mentioned, this method may elicit practical issues for athletes with a SCI.[36, 39]

4 Summary of cooling methods and timing of cooling application

In comparison to the advice that can be gathered from the literature for able-bodied athletes it is difficult to establish the optimal cooling method for athletes with a SCI. This is predominantly due to the lack of studies that have investigated the use of cooling strategies in this population leading to a lack of evidence for each method (Table 2). Nevertheless, from the studies reviewed it would appear that wearing an ice vest during intermittent sprint exercise has beneficial effects both in terms of decreasing thermal strain and enhancing performance,[64] though contrasting findings have been observed during steady state exercise.[49] Drawing on findings from the able-bodied, the use of ice vests has been shown to be a feasible method of pre-cooling, with a 4.8% improvement in performance[53] in addition to improved performance from wearing the garments during exercise in the heat.[30] A combination of pre-cooling and cooling during exercise or half-time cooling might also be an effective strategy.[30]

Although not currently studied in athletes with a SCI, the consumption of cold beverages, in particular ice slurries, have been shown to be an effective pre-cooling method in the able-bodied by lowering T_{core} and improving endurance performance in the heat.[74] Further investigation into this internal method is warranted but could be studied as a practical cooling alternative for athletes with a SCI. The specific sporting regulations and logistics of administering any cooling method for athletes with a SCI in wheelchair court sports needs to be carefully considered.

5 Limitations and future research

The majority of studies reviewed had a SCI group consisting of individuals with paraplegia and tetraplegia, potentially affecting the groups mean thermal response, due to an individual's thermoregulatory response being proportional to lesion level.[10] Thermoregulatory responses may also depend on the completeness of the injury[75] with incomplete lesions resulting in a greater amount of sensory information about their thermal state and a greater capacity to sweat.[64] Therefore, studies should separate individuals with paraplegia and tetraplegia in population groups and note the number of individuals with incomplete lesions, providing justification for their inclusion in the sample.

Overall the studies reviewed neglected to employ a standard measure of performance specific to the sport, making it difficult to determine if there is a clear performance benefit associated with a cooling strategy. For application in wheelchair court sports future research should consider employing an ISP that reflects the nature and exercise intensity of the sport. The mode of exercise also needs to be appropriate as differences in thermoregulation are elicited depending on the modality, i.e. arm crank vs. wheelchair ergometry.[42]

Only one of the eight studies reviewed mentioned the use of a warm-up and the application of cooling during this time. Often an athlete's warm-up is performed at intensities (~40-60% $\dot{V}O_{2max}$, able-bodied research)[76] that result in an increase in T_{core}. Therefore, excluding a warm-up from the experimental design could affect the practical application of the findings of the reviewed studies. Prospective studies need to ensure the inclusion of a warm-up and, if pre-cooling is being administered, the wearing of cooling garments during this time, if appropriate.

Future studies need to be as closely matched as possible to the intended environmental playing conditions. In relation to wheelchair court sports, athletes with a SCI predominantly compete in: wheelchair tennis, wheelchair rugby or wheelchair basketball. The latter two sports are played indoors, suggesting that it should be possible to closely control the ambient playing conditions. How strictly these indoor conditions are regulated is unclear, i.e. air conditioned, with anecdotal evidence suggesting playing conditions vary greatly between training centres and competition venues. In addition to this, the increased potential for thermal strain owing to the intermittent sprint nature of the sports and the impaired thermoregulatory response of individuals with a SCI suggest that cooling strategies could be highly beneficial for athletes with a SCI in these sports. In wheelchair tennis, guidelines are put in place by the International Tennis Federation (ITF) to ensure wheelchair players are not put at an increased risk of heat injury. Guidelines include a wet bulb globe temperature index (WBGT) limit of 28°C, provision of shade and ice buckets on court and scheduling of matches morning or late afternoon/evening.[77] It should be noted that to implement a structured pre-cooling strategy in this sport may be potentially difficult due to the unknown start time caused by previous extended play. In all wheelchair sports, due to the practical problems of travelling to venues, athletes with a SCI may arrive at a match with an elevated T_{core}, especially in high ambient temperatures and/or humidity. Without sufficient cooling or recovery this may limit their temperature margin before reaching a critical T_{core} during exercise.

Future studies are required to establish the transferability of practical cooling strategies in a laboratory to the field environment.[35] To achieve this, future work should attempt to replicate actual competition and practical limitations experienced in “real-life” situations. This includes participants of a highly trained and motivated nature to ensure research findings can be translated into meaningful performance enhancements[35] in the athletic SCI population.

6 Practical recommendations

While research is lacking and inconclusive, several practical recommendations can be suggested.

- Sport scientists must adopt an individualised approach and refine the cooling strategy based on the sport and the athlete’s level and completeness of lesion.

- The sporting regulations, effectiveness, practicality, staffing/assistance, logistics, cost and athlete comfort of a cooling strategy need to be considered. For example, hand cooling may be impractical for some athletes with a SCI due to their limited hand grip function and the use of gloves during play.

- Athletes and coaches must trial cooling strategies prior to their use in competition to determine the suitability of a strategy. For instance, the appropriate fit of an ice vest would need to be determined to ensure upper body mobility is not affected and abdominal binding/strapping can still be used.

- The cooling power of a cooling method must be considered and where possible a combination of practical and portable cooling methods should be used to increase the effectiveness of a cooling strategy. One example would be to use an ice vest prior to a match and water sprays during rest periods/half-time. Which combination of cooling is the most effective would heavily depend on the practicality of the methods for the particular sport.

- Coaches and support staff need to be educated on the signs and symptoms of heat illness. This will enable them to recognise when a player needs to stop playing, be removed from the environment and cooled with an appropriate cooling strategy. Notably, Webborn et al.[78] stopped two participants during the ISP as their T_{core} had reached the safety limit (39.3°C or a 2°C increase from rest). Therefore, it is crucial that coaches and support staff can identify players with heat illness symptoms, such as extreme fatigue and dizziness, which will greatly affect their decision making ability during play.

- It is imperative that sports venues are air conditioned and ice is provided at the competition venues. Water sprays and fans should also be provided for use during time-out/ half-time. Both techniques should lower perceptual responses of thermal sensation and comfort, whilst fanning should increase heat loss by convection.[79] Although, if athletes are substituted for a long period of time they should be careful not to overcool, especially as athletes with a SCI possess a smaller surface area for temperature perception.

- Athletes must ensure that they are hydrated and ingest adequate fluid during play. However, to avoid autonomic dysreflexia athletes should ensure they void their bladder prior to play.

- An acclimation strategy must be considered for athletes who compete outdoors or who are likely to spend considerable time transferring to sports venues (e.g., competitor at the Paralympic Games). Partial heat acclimation may be possible for athletes with a SCI. For instance, Castle et al.[80] demonstrated a lower resting T_{core} and increased plasma volume, but no improvement in sweat response, following 7 days of heat acclimation in athletes with a SCI.

- Medications and sleep deprivation may affect an athlete's heat tolerance[43] and should be addressed with the athlete to minimise the risk when the athlete is travelling or competing in a warm environment.

7 Conclusion

Due to the thermoregulatory impairment of athletes with a SCI, employing cooling strategies in this population group could be beneficial to offset any decrement in performance. From the studies reviewed wearing an ice vest during intermittent sprint exercise has a beneficial effect on both decreasing thermal strain and enhancing performance. These garments have also been shown to be effectively used prior to and during exercise in the able-bodied population. Drawing on additional findings from the able-bodied, a combination of pre-cooling and cooling during exercise or half-time cooling might increase the effectiveness of a strategy.[30, 31] However, to date, there has been a lack of studies addressing fundamental issues regarding which cooling strategy is the most appropriate in terms of method, timing, duration, and body region cooled in a competition environment for athletes with a SCI. Future studies should employ cooling strategies under constraints of actual competition with highly trained athletes with a SCI and appropriate exercise protocols to ensure research findings can be translated into meaningful performance improvements. The specific sporting regulations and logistics of administering a cooling method in wheelchair court sports need to be carefully considered. Sport scientists and coaches should take an individualised approach when refining a strategy and conduct their own tests of a cooling strategy prior to its use in competition.

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