Crushed ice ingestion – a practical strategy for lowering core body temperature

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Abstract

Exercise together with environmentally induced heat stroke continue to pose a problem for military operations in hot climates. A variety of cooling strategies are required by the military to mitigate the risk of heat stroke due to the variety of climates and physical workloads encountered by defence personnel, combined with their individual physical characteristics and uniforms/protective attire. This paper highlights that cooling is traditionally applied as a treatment for heat stroke rather than used to prevent its onset. Recent evidence from the field of sport science demonstrated that cold fluid consumption can act as a heat sink to blunt the rise of core body temperature. Furthermore, the addition of crushed ice to beverages substantially improves its heat storage potential, resulting in decreased core body temperature and enhanced endurance performance. While crushed ice will not be universally available in defence settings, it is a strategy that requires minimal equipment, is relatively quick to prepare, is not labour intensive and does not require the removal of a soldier's uniform. The military should therefore consider the use of crushed ice ingestion as a preventative measure against heat stroke.

Key words: crushed ice ingestion, hyperthermia, cooling, heat stroke

Exercise and Environmentally Induced Heat Stroke

Exercise and environmentally induced heat stroke (EEHS) describes inadequate heat loss and/or excessive endogenous heat production during exercise[1], and is diagnosed by a core body temperature greater than 41°C and altered cerebral function. Given the variety of climates and physical workloads encountered by military personnel, combined with their individual physical characteristics and uniforms/protective attire, it is not surprising that EEHS and other heat related illnesses threaten the health of defence force personnel. The risk and incidence of EEHS in military settings is well described[2-10], with the duration and degree of core body temperature elevation considered as the primary predictors of patient outcome[11]. That 37 US Army soldiers died and a further 5248 required hospitalisation for heat illness from 1980 to 2002 highlights this point.[12] Within an Australian context, 65 cases of heat related illnesses were reported over a 15 week period (2003/4) during training courses conducted in tropical field conditions, inclusive of one death[13]. A more recent report illustrates that hot climates continue to influence global military operations, with 311 cases of EEHS reported among a total of 2887 heat related injuries within the US Armed Forces during 20102.

A wide variety of strategies are required to combat the development of, and to treat, EEHS. Strategies preparing defence force personnel for hot conditions include heat acclimatisation[4] and improved physical fitness[14]. Heat acclimatisation is a key strategy to improve tolerance of hot conditions as the majority of heat related illnesses occur within the initial days of deployment to the new environment[15]. Maintaining an adequate hydration status [16], pacing of effort and work to rest guidelines[17] seek to limit heat storage to manageable levels and can be broadly classified with heat acclimatisation and physical fitness as preventive measures for development of EEHS. In contrast, cooling is generally classified as a treatment for EEHS, with the objective of rapidly lowering core body temperature to minimise the degree and duration of hyperthermia. The majority of military and occupational cooling research has therefore been dedicated to lowering the core body temperature of symptomatic patients or athletic subjects with exercise induced hyperthermia, with cold water immersion demonstrating the fastest cooling rates and therefore the preferred cooling method to counter EEHS[18,19]. The limitations of relying on cold water immersion in the Australian military setting have been highlighted by McKenzie[20], with limited access to adequate volumes of ice in the field the primary constraint. Alternatives to cold water immersion include enhancing evaporation and/or convection by fanning[21], spraying/dousing with water[22], resting in the shade[22], resting in an air conditioned area[23], personal cooling systems[24] and the administration of cool intravenous fluids[25]. Conduction based cooling methods include the application of ice packs[26] cooling blankets[27], limb water immersion[28], temperate whole body water immersion[23], and ice-wet towels[29]. Use of the aforementioned methods and a combination thereof generally achieves protracted cooling times when referenced against cold water immersion[27], resulting in the recognition of cold water immersion as the gold standard for treatment of exercise and environmental heat stroke[30]. Regardless, the alternate strategies to cold water immersion may be the most appropriate cooling treatment for EEHS where access to adequate volumes of cold water is not possible. Management of core body temperature may also be aided by the aforementioned modalities prior to the classification of EEHS. The aim of cooling provided during scheduled rest periods is to prolong exposure time by limiting the development of high core body temperatures. Such an 'intermittent cooling' approach is considered proactive, seeking to regulate an individual's physiological state to prevent EEHS, rather than to treat it. The field of sport science has utilised intermittent cooling and cooling applied prior to competition (pre-cooling) to improve physiological responses and in most cases physical performance of athletes competing in hot conditions[31]. The constraints of most athletic competitions dictate that prerequisites for cooling techniques are minimal equipment, time efficiency, ability to be deployed in the field and not labour intensive. Similar constraints may coexist in a variety of military settings. With this in mind, practical field deployable cooling strategies are required to improve tolerance and decrease the incidence of EEHS.

Cooling by Cold Fluid Consumption

A potential intermittent cooling mode for select military settings is the ingestion of cold water. It is well established that beverage consumption benefits physiological, perceptual and performance outcomes during endurance activities in the heat, compared to fluid abstinence[32,33]. Fluid consumption can also directly influence core body temperature as a result of the heat transfer between the beverage and the gastrointestinal tract. The specific heat capacity of water dictates that ~4.2 kJ of energy is required to heat 1 kg of water by 1°C. Researchers have utilised the heat capacity of ingested beverages to lower core temperature following ingestion of cold fluids in comparison to beverages served at near core body temperature (37-38°C). Wimer et al.[34] demonstrated a small core temperature benefit when consuming ~1.35 L of fluid served at 0.5°C compared to 38°C during the latter stages of moderate physical activity in warm conditions. This study provided fluids following the initial hour of exercise by which time substantial heat storage had occurred. The cold fluids blunted the rise of core temperature by ~0.14°C. The outcomes of this study were insufficient to warrant cold fluid ingestion as the benefits were small and the timing of fluid consumption was vastly different to practices in the field. Lee et al.,[35] utilised a more common approach of pre-loading with 0.9 L of fluid during the 30 minutes preceding physical activity, combined with periodic consumption (0.1 L/10 minutes) during submaximal exercise until exhaustion, to compare responses to 4°C and 37°C fluid.

Consumption of the cold beverage resulted in a 0.5°C core body temperature decrease prior to exercise, with core body temperature remaining significantly cooler until the 45th minute of the performance trial. Perceptual ratings and time to exhaustion (~64 v ~52 minutes) also benefited, highlighting the potential of cold fluid consumption. However, the reported benefits are tempered by both experimental designs using warm fluids served at similar temperatures to that of deep tissue temperature and much warmer than the preferred beverage temperature of 15-20°C[36]. When ad libitum consumption was compared between cold (1.3 L at 4°C) and a more common beverage temperature (1 L at 19°C) during submaximal cycling to exhaustion, the core body temperature benefit was reduced to 0.25°C at the cessation of cycling. in spite of the greater cold fluid consumption[37]. The small benefit reported by Mündel et al.,[37] may be slightly underestimated as subjects cycled for an extra seven minutes (~62 v ~55 minutes) during the cold fluid trial. However, the results are more likely explained by the limited cooling power of the ingested drink. With less than half the difference (15°C) between the experimental beverage referenced to other studies[34,35], the ingested heat capacity was ~63 kJ compared to ~140 kJ and ~158 kJ for Wimer et al.[34] and Lee et al.[35] respectively. While preferable over warm fluids, the small benefit for a relatively large volume of fluid suggests that cold fluids cannot be independently relied upon to substantially improve the heat storage capacity of military personnel in hot settings.

Cooling by Ice Ingestion

The limited cooling capacity of cold fluids could be enhanced by the addition of ice to beverages as the conversion of ice to water utilises the latent heat of melting to theoretically absorb more heat than an equivalent volume of cold fluid. One litre (L) of ice requires ~334 kJ to melt, and once in a liquid form the heat storage capacity mirrors that of a cold ingested beverage. Hence, the potential heat storage conferred by 1 L of crushed ice is ~489 kJ to melt and warm to 37ºC, compared to ~155 kJ for cold water (0ºC) to reach 37ºC. Despite being recommended as a potential cooling option in athletic settings,[38] few published reports of the physiological responses to crushed ice ingestion are available. A small field of research has demonstrated the potential of crushed ice ingestion (CII), commonly known as 'slushies' as a practical cooling modality. When compared to the ~0.2ºC core body temperature decrease observed from rest for temperate water consumption (26ºC), CII resulted in a significantly greater (~1.1ºC) core temperature improvement prior to physical activity[39]. In that study, 150-200 g of crushed ice was consumed every 8-10 minutes over a 30 minute period, resulting in subjects ingesting ~553 g on average, or 6.8 g/kg body mass. Although the true core temperature benefit is likely to be overestimated due to the susceptibility of ingestible core body temperature sensors to local cooling of the gastrointestinal tract[40], 40 km cycling time trial performance improved in the hot conditions with mean power output 6.9% higher following ice ingestion with similar core body temperatures observed during the trial. Siegel et al.[41] used a similar ice ingestion schedule (1.25g/kg-1 body mass every 5 minutes) to deliver an average ~600 g of crushed ice, the equivalent of 7.5 g/kg body mass over 30 minutes. Importantly, the comparison beverage was served at 4ºC and demonstrated a 0.25ºC decrease in core body temperature prior to exercise compared to the 0.66ºC observed following CII. Core body temperature remained cooler pursuant to CII for the initial 30 minutes of the running trial. The significance of this study is that it demonstrated a worthwhile benefit for CII over cold water consumption, which in turn, is superior to drinking warm fluids[35]. The moderately trained subjects also improved running time to exhaustion in hot conditions from 40.7 (cold water) to 50.2 minutes following the slushie. With a quantified benefit for CII, the strategy was combined with the use of ice wet towels to compare against ad libitum cold fluid consumption and whole body cold water immersion[42]. Dual boluses of 7g/kg body mass were consumed across 30 minutes (14g/kg body mass) by well trained athletes with their torso and legs draped in ice-wet towels. Prior to performance, cold water immersion demonstrated the greatest core body temperature cooling effect (~0.6ºC), significantly cooler than CII (~0.3ºC), which in turn, was significantly cooler than ad libitum cold fluid consumption (~0.0ºC). These results were reversed during the subsequent 46.4km cycling time trial in hot conditions, with no statistical difference in the core body temperature response, notwithstanding the higher power output sustained following CII (~3% higher than cold fluid and ~2% highe than cold water immersion). Despite these studies demonstrating lower core body temperatures and improved endurance performance in the heat, performance is not universally improved following CII.

To test the effectiveness of crushed ice ingestion following substantial heat storage (core body temperature 38.9ºC), moderately trained cyclists ingested 1 L of slushie or cool fluid (~18ºC) during a 50 minute recovery period[43]. CII resulted in mean core body temperature of ~37.0ºC compared to ~37.4ºC following the cool beverage. Time to complete a set amount of work did not differ between trials, despite the cyclists lower core temperature during the initial stages of the performance trial. While endurance performance did not alter, this study demonstrated that intermittent cooling via crushed ice ingestion is an effective modality to lower core temperature of athletes between exercise bouts.

Occupational Settings

Unfortunately, less is known of the response to CII in occupational settings. A recent investigation to examine intermittent cooling of fire fighters in tropical field conditions found no core body temperature benefit for CII compared to ad libitum cool fluid consumption during rest periods[44]. The fire fighters were unable to ingest the 7.5g/kg body mass bolus, allowing much of the ice to melt prior to consumption and forfeiting its cooling potential. Since the fire fighters could not match the CII of athletes, alternative ingestion schedules ought to be examined. Another approach is to provide ad libitum access to crushed ice and cold fluids, allowing self regulation of consumption. Such an approach during simulated mining resulted in the miners consuming 34% less crushed ice when compared to cold fluids[45]. Despite the lower ice consumption, core temperature was not different between the groups due to the superior cooling power of ice. The impact of ad libitum CII remains poorly understood, and while many factors contribute to ad libitum fluid consumption, the cooler thermal sensation following CII may diminish the drive to drink. Such an outcome over an extended period may limit the ability of CII to influence core body temperature and also manifest in dehydration.

The threshold ingestion volume to improve thermoregulatory and performance responses also remains to be investigated, and is likely to vary based upon the task, uniform/protective attire and environmental conditions. In the absence of specific guidelines, consumption of 4-5 g/kg body mass of crushed ice for soldiers during scheduled breaks of ~15 minutes seems a logical starting point. For an 80kg soldier consumption of 320-400 g of ice over a 15 minute period does not seem onerous, yet it would provide 156-196 kJ of cooling compared to 44-55 kJ of cooling for the equivalent volume of 4°C fluid. Whether soldiers could repeatedly consume such a volume of ice to prevent EEHS remains to be tested.

The logistics of providing crushed ice for soldiers are vastly different to those encountered when providing for small groups of athletes. Availability of adequate volumes of ice in the field will be a challenge. Within the Northern Territory, power and water utility crews have access to ice machines at each depot, allowing for ice transportation to work sites. McKenzie[20] details a similar system will exist on Australian military bases allowing training platoons to take ice into the field to be used with water and an individual sleeping shelter as a makeshift immersion bath. Whether adequate volumes of ice can be stored and transported for training platoons to use for treatment (immersion) and prevention (CII) of EEHS remains to be determined. Therefore, military bases are the ideal starting point for field testing. Should CII prove to be a worthwhile strategy during training on base, the logistics of CII in remote field settings will warrant addressing.

Conclusions and Recommendations

The limited research to test the ingestion of ice as a cooling modality reports lower core body temperatures before and during scheduled breaks in physical activity. Core body temperatures during the initial stages of exercise are generally lower following CII while also improving endurance performance for athletes. Based upon these findings, CII is worthy of consideration as a cooling modality in military and occupational settings as a preventative measure for EEHS. While its application is limited by the availability of ice, a slushie requires minimal preparation and can be administered without the removal of uniforms. Military bases appear the logical starting point to evaluate this strategy given the access to ice.

Research should test the ability of military personnel to consume adequate volumes of ice in a short time frame. The threshold ingestion volume to improve thermoregulatory and performance responses is yet to be determined, however 5g/kg body mass over a 10-15 minute period seems a logical starting point. Ad libitum fluid consumption following CII should also be examined. It is possible that internal cooling following CII may diminish the drive to drink, thereby lowering ad libitum fluid consumption and manifesting in dehydration.

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