Effects of Pre-Exercise Ice Slurry Ingestion on Physiological and Perceptual Measures in Athletes with Spinal Cord Injuries

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EFFECTS OF PRE-EXERCISE ICE SLURRY INGESTION ON PHYSIOLOGICAL AND PERCEPTUAL MEASURES IN ATHLETES WITH SPINAL CORD INJURIES

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ABSTRACT

EFFECTS OF PRE-EXERCISE ICE SLURRY INGESTION ON PHYSIOLOGICAL AND PERCEPTUAL MEASURES IN ATHLETES WITH SPINAL CORD INJURIES

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Athletes with spinal cord injuries (SCI) have an impaired ability to thermoregulate during exercise, leading to an increased core temperature (T_{core}) due to a decrease in sweat response. Elevated core temperature may result in premature onset of fatigue and decreased athletic performance. Therefore, precooling techniques that decrease T_{core} before exercise may increase the storage capacity for metabolic heat production, thereby improving exercise performance. The purpose of this study was to investigate the effects of pre-exercise ice slurry ingestion as a precooling method in elite athletes with SCI during a match simulation. Employing a field-based, counterbalanced-design, subjects were administered 6.8 g/kg of room temperature (PLB) or ice slurry (IS) beverage during a 20 minute precooling period, before engaging in a 50 and 60 minute on-court training session on day 1 and 2, respectively. Physiological measures, including T_{core} and heart rate, and perceptual measures including gastrointestinal and thermal comfort, and rating of perceived exertion, were monitored throughout precooling (minutes 10, 20) and exercise (minutes 10-60). IS had a large effect on T_{core} at the midpoint of exercise on day 1 (minute 30) (ES = 0.73) and 2 (minute 40) (ES =

1.17). Independent samples T-tests revealed significant differences in the perception of thermal comfort between IS and PLB at the midpoint of exercise on both day 1 (minute 30) ($P = 0.04$) and 2 (minute 40) ($P = 0.05$), indicating that IS helped subjects to feel cooler during exercise. In conclusion, pre-exercise ice slurry ingestion provides an effective means for delaying an increase in T_{core} in athletes with SCI.

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CHAPTER I

INTRODUCTION

Athletes with spinal cord injuries (SCI) face challenges unlike those of able-bodied (AB) persons, including altered sweat rate, delayed gastric emptying, and smaller working muscle mass (Goosey-Tolfrey, 2014). Reduced afferent signals to the thermoregulatory center results in greater increases in core temperature (T_{core}) in athletes with SCI compared to AB counterparts (Griggs et al., 2015). Furthermore, athletes with SCI have altered autonomic nervous system control, which results in a reduced sweat response below the level of injury (Pritchett et al., 2015). Blood-flow redistribution and sweating are two major thermoregulatory effectors, suggesting that athletes with SCI have impaired ability to thermoregulate during exercise as the body cannot dissipate heat at the rate which it is internally produced (Forsyth et al., 2016; Griggs et al., 2015; Price, 2006). Athletes with a higher level and completeness of spinal lesion may experience greater difficulty maintaining T_{core}. Therefore, as the result of impaired ability to maintain T_{core}, athletes with SCI may experience premature onset of fatigue and decreased performance especially when exercising in the heat (Forsyth et al., 2016).

A number of precooling techniques have been investigated as a means of reducing T_{core} before exercise in order to increase the available temperature margin before reaching a critical level (Griggs et al., 2015). Lessening heat stress may lead to improved performance in both AB and SCI subjects (Webborn et al., 2010; Goosey-

Tolfrey et al., 2008; Griggs et al., 2015), however, some researchers have suggested that there is little evidence to support improved performance following precooling in AB populations (Jones et al., 2012). Webborn et al. (2010) compared the use of cooling vests before and during exercise in the heat (32°C, 50% RH) during an intermittent sprint protocol with wheelchair rugby and tennis athletes. Compared to the control (no cooling), subjects wearing a cooling vest were able to sprint longer (52.8 minutes DUR, 47.2 minutes PRE, 36.2 minutes CON; $P < 0.05$) and perform 6-8 more sprints ($P < 0.05$). Furthermore, an increase in T_{core} was significantly ($P < 0.01$) delayed for the precooling trial, as compared to both the during exercise and control conditions (Webborn et al., 2010). Forsyth et al. (2016) reported similar findings in subjects with SCI, with cold water immersion (CWI) eliciting a greater cooling effect ($P < 0.05$) than ice slurry ingestion and site-specific cooling methods during 60 minutes of passive rest (Forsyth et al., 2016). While the efficacy of CWI and cooling garments in both AB athletes and athletes with SCI is established in the literature (Webborn et al., 2010; Goosey-Tolfrey et al., 2008; Forsyth et al., 2016), these precooling strategies may not prove practical for competition-like settings. CWI tanks require significant monetary investment and are not practical for travel, nor for athletes with SCI as athletes must be lifted in and out of the tank. Likewise, cooling vests may not be practical for the uniform attire required during match play and are single site specific.

Ice slurries are icy mixtures consumed as a beverage that may be a practical and affordable precooling method to decrease T_{core} before exercise, in turn increasing time to exhaustion (Siegel et al., 2010; Yeo et al., 2012). Some studies have investigated cold water ingestion as a cooling modality (Ross et al., 2011; Siegel et al., 2010), however, solid ice ingestion may provide a greater cooling effect than water due to "enthalpy of fusion" (Siegel et al. 2010). When ingesting ice slurry as a cooling technique, greater amounts of internal heat may be transferred to the drink as it changes phase from solid ice to water (Siegel et al., 2010). Following a pilot study that identified a large effect on T_{core}, Ross et al. (2011) concluded that the combination of a large volume (1 kg) slurry with iced towels was a novel precooling method. During a subsequent study in which trained cyclists completed a time trial in hot conditions (32°C-35°C at 50%-60% RH), subjects who precooled using both ice slurry (14 g/kg) and iced towels for 30 minutes before exercise demonstrated a 3.0% increase in power output (~8 W, $P = 0.04$) and a 1.3% improvement in performance time (~1:06 min, $P = 0.08$) compared to the control trial (Ross et al., 2011). Similarly, Siegel (2010) examined the difference between 7.5 g/kg of ice slurry (-1°C) and cold water (4°C) ingestion consumed during a 30 minute precooling period on run performance in the heat in AB subjects (Siegel et al. 2010). Following ice slurry ingestion, running time was longer (50.2 ± 8.5 min, $P = 0.001$) and rectal temperature remained lower for the first 30 minutes of exercise ($P = 0.001$) versus cold water (40.7 ± 7.2 min) ingestion (Siegel et al., 2010). However, other studies examining the effectiveness of an ice slurry in AB subjects have found no significant difference in performance (Siegel et al., 2012).

Forsyth et al. (2016) compared the effects of cold water immersion (CWI), ice slurry ingestion (S), and ice slurry ingestion plus the application of iced towels (ST) in wheelchair basketball athletes during 60 minutes of passive rest (Forsyth et al., 2016). After the 20 minute precooling period, the greatest cooling effect was observed for CWI, with subjects demonstrating the largest differences in T_{core} at 60 minutes into passive rest; T_{core} for CWI was 1.58°C (95% CI [1.07,2.10]) lower than CON, 1.46°C (95% CI [0.95,1.97]) lower than S, and 1.10°C lower than ST (0.58,1.61) (Forsyth et al., 2016). To date, Forsyth and colleagues (2016) are the first to examine the efficacy of ice slurry ingestion as a precooling method in subjects with SCI. While researchers failed to observe significant changes in T_{core} after ice slurry consumption, it was suggested that the volume of ice slurry administered could prove beneficial if exercise began immediately after ingestion (Forsyth et al., 2016). However, Forsyth et al. did not employ an exercise protocol to raise core temperature after precooling.

Therefore, the purpose of this study was to investigate the effects of pre-exercise ice slurry ingestion as a practical and affordable precooling strategy on physiological and perceptual measures during an on-court session in elite athletes with SCI.

CHAPTER II

LITERATURE REVIEW

Introduction

According to data from the National Spinal Cord Injury Statistical Center, approximately 17,500 new cases of spinal cord injury (SCI) occur in the United States every year (NSCISC, 2017). As of 2017, it is estimated that 285,000 persons in the United States are living with a spinal cord injury (NSCISC, 2018). Spinal cord injuries lead to lifelong impairment and disability, significantly impacting quality of life, both directly and indirectly (Dijkers, 1997). It is well-known that participation in physical activity and sport generates positive health effects, and both are included in many rehabilitation programs for people with disabilities, including spinal cord injuries (Fagher et al., 2016). Adaptive sport provides sporting opportunities for athletes with disability, ranging from grassroots to elite levels (Fagher et al., 2016). Since its inception in 1960, the Paralympic Games has grown from just 400 athletes from 23 countries participating in 13 sports to more than 4,300 athletes competing in 22 sports and representing 159 countries during the 2016 Paralympic Games in Rio de Janeiro ("Rio 2016"). Many Paralympic athletes today have reached performance levels similar to that of elite able-bodied athletes with the increase in number of Paralympic athletes, and developments in sports performance and technology (Fagher et al., 2016). Athletes with SCI face a number of challenges unlike those of able-bodied persons, ranging from but not limited to smaller working muscle mass, delayed gastric emptying, and reduced sympathetic nervous system (SNS) activity.

Physiology of Spinal Cord Injuries

The spine is comprised of 33 vertebrae which are divided into five types: cervical, thoracic, lumbar, sacral, and coccygeal (Jones Irwin, 2016). Injury to the thoracic or lumbar vertebrae cause functional loss in the legs and trunk, as well as in the muscles and organs which are innervated below the level of lesion, resulting in paraplegia (Jones Irwin, 2016). Similarly, injury to the cervical vertebrae results in functional loss in all four extremities, with damage the nerves innervating the head, neck, trunk, diaphragm, arms, and hands, and is defined as quadriplegia (Jones Irwin, 2016).

In addition to classification by the level of lesion, spinal cord injuries can be defined as complete or incomplete based on the degree of motor and sensory loss (Jones Irwin, 2016). Complete SCI is defined as a loss of all function, both motor and sensory, below the level of lesion (Jones Irwin, 2016). Conversely, incomplete SCI indicates neurological function below the level of the injury may vary, whereby there may be complete motor loss but incomplete sensory loss, or vice versa (Jones Irwin, 2016). Incomplete SCI are highly variable among individuals, as one individual may experience sensation or have voluntary movement, while others may not (Jones Irwin, 2016).

A smaller working muscle mass may further contribute to reductions in functional capacity. Muscle wasting is observed below the level of lesion in athletes with SCI; however, higher percentages of lean mass in the upper body may compensate for smaller percentages of lean mass in the lower body (Goosey-Tolfrey, 2014). This leads to lower energy requirements during training, as well as a reduction of physical work capacity as measured by VO_{2peak}, VO_{2max}, and maximal power output as compared to able-bodied counterparts (Goosey-Tolfrey, 2014). Measures of standard lab-based tests for aerobic capacity are reduced in proportion to the level of lesion, with quadriplegic athletes demonstrating the lowest values for VO_{2peak} and peak heart rate, when compared to paraplegic athletes (Goosey-Tolfrey, 2014).

Thermoregulatory Challenges in Athletes with Spinal Cord Injury

Athletes with SCI have an impaired ability to thermoregulate during exercise, which is of particular concern as reduced afferent information to the thermoregulatory center results in greater increases in core temperature (T_{core}) as compared to able-bodied persons (Griggs and Price et al., 2015). Furthermore, athletes with SCI have weakened autonomic nervous system control, which results in a reduced sweat response below the level of their spinal cord injury (Pritchett et al., 2015). As blood-flow redistribution and sweating are two major thermoregulatory effectors, this suggests that athletes with SCI have an impaired ability to thermoregulate during exercise, as the body cannot dissipate heat at the rate at which it is internally produced (Forsyth et al., 2016; Griggs, Price, and Goosey-Tolfrey, 2015; Price, 2006). Athletes with a higher level and completeness of the spinal lesion may experience greater difficulty maintaining T_{core}. Research has shown that as compared to athletes with paraplegia, athletes with quadriplegia tend to drink greater volumes of fluid during exercise, likely due to the inability to sweat effectively and increased body temperature from exercise (Goosey-Tolfrey, 2014). This may lead to overhydration, as well as increased body mass from drinking (Goosey-Tolfrey, 2014). Additionally, athletes with SCI should be mindful when consuming large amounts of fluids as to not trigger autonomic dysreflexia, a condition in which an exaggerated release in norepinephrine triggers dramatic increases in blood pressure (Price, 2006).

As a result of an impaired ability to maintain T_{core}, athletes with SCI may experience a premature onset of fatigue and decreased performance (Forsyth et al., 2016). As such, a number of precooling techniques have been identified and investigated as a means of reducing core temperature prior to exercise in order to increase the available temperature margin before T_{core} reaches a critical level (Griggs, Price, and Goosey-Tolfrey, 2015).

Precooling

The goal of precooling is to both increase the storage capacity for metabolic heat production, while also delaying the onset of thermally-induced fatigue (Griggs et al., 2015; Forsyth et al., 2016). Increased core temperature is commonly cited as one of the main reasons for decreased athletic performance, especially in endurance events (Gonzalez-Alonso and Teller, 1999). Research shows that as core temperature rises, athletes will experience decreased endurance performance and capacity, in addition to a faster onset of fatigue and decreased time to exhaustion (Goosey-Tolfrey et al., 2008;

Siegel et al., 2010). In a 2012 meta-analysis of 27 peer-reviewed, randomized control trials examining the effects of precooling in both trained and elite able-bodied athletes, Wegmann and colleagues found that precooling results in an average performance enhancement of 4.9%, with the largest effects seen in athletes competing in hot environments and endurance events (Wegmann et al., 2012).

Although exact mechanisms remain unclear, precooling is thought to provide an ergogenic effect by way of multiple body systems. As the body heats, the cardiovascular system redistributes blood flow from the periphery to the body core in attempts to lower heat strain (Thomas, Erdman, and Burke, 2016). At the same time, blood vessels of the skin begin to vasodilate in order to dissipate heat, resulting in increased skin temperature (Thomas, Erdman, and Burke, 2016). Likewise, metabolic processes are altered in order to preserve optimal body temperature for enzymatic activity and maintain homeostasis (Thomas, Erdman, and Burke, 2016).

Precooling techniques are categorized as either external or internal. External cooling techniques are defined as cooling agents applied to the outside surface of the body (Ross et al., 2013). Exposure to cold air or cold water, such as an ice bath, as well as the application of ice-cold garments like vests or towels are common external cooling methods. The majority of precooling techniques are applied externally; therefore, most research has focused on the effectiveness of external precooling techniques. However, the practicalities of external precooling modalities must be considered when making recommendations for athletes. Cold water immersion tanks require significant monetary investment and are not practical for travel. Likewise, cooling vests and neckbands may not be practical for the uniform attire required during match play and are specific to a single body site. Additionally, cooling garments may be heavy, and interfere with play.

Conversely, taking a cold medium into the body via the mouth or nose is defined as an internal cooling technique (Ross et al., 2013). Internal cooling modalities provide additional benefits compared to external techniques in that when a cold medium is taken into the body, it may delivers nutrients and can also promote sensory advantages (Ross et al., 2013). External cooling methods may result in subjective cooling, without a change in T_{core} (Trbovich et al., 2014). While a “feeling” of coolness may result in athletes working harder or longer, subjective cooling may mask an elevated T_{core}, and prevent rehydration (Trbovich et al., 2014). Therefore, ingesting a cooling medium may be more desirable in that athletes can both cool and hydrate, which is effective if dehydration is likely. Furthermore, internal cooling methods cool the body without negatively influencing muscle temperature before exercise.

In addition to the type of cooling method, timing and duration of the precooling period are key considerations. To achieve any significant reduction in T_{core}, both internal and external cooling methods require at least 15 to 60 minutes (Griggs, Price, and Goosey-Tolfrey, 2015). However, it is important to find the balance between effective cooling and athlete comfort. Precooling should not compromise the pre-event or half-time routine, and athlete comfort is crucial for performance (Griggs, Price, and Goosey-Tolfrey, 2015).

Ice Slurry

Ice slurries, or slushies, are icy mixtures that are consumed as a drink and may be a practical and affordable method to decrease T_{core} prior to exercise (Siegel et al., 2010). While some studies have investigated cold water ingestion as a cooling modality (Ross et al., 2011; Siegel et al., 2010), it is thought that solid ice ingestion may provide a greater cooling effect than water alone due to "enthalpy of fusion" (Siegel et al., 2010). When ingesting ice slurry as an internal cooling technique, a greater amount of internal heat may be transferred to the drink as it changes phase from solid ice to water, resulting in a greater cooling effect than cold water alone (Siegel et al., 2010). Initial calculations estimated that when a 70-kg subject ingested 1L of 7°C water, T_{core} would be reduced by ~0.5°C (Ross et al., 2011). Research found that when tested, the actual reduction in T_{core} was observed to be 0.61°C $\pm$ 0.13°C at its maximum point, 20-25 minutes after fluid ingestion (Ross et al., 2011). Furthermore, core temperature was observed to remain 0.31°C $\pm$ 0.13°C lower, as compared to control, 55 minutes after drinking the cold fluid (Ross et al., 2011). With these findings, researchers then hypothesized that taking in ice, rather than a cold fluid, may be an effective internal cooling method. Furthermore, unlike other external cooling modalities, ice slurries are both practical for travel and game situations, and are affordable.

It has recently been proposed that the ergogenic effect of ice slurry ingestion can be attributed to central nervous system function. Webborn et al. (2010) examined the effect of elevated T_{core} during repeated sprint performance in athletes with tetraplegia and suggested that impairments in performance were not related to metabolic factors, but instead the result of high T_{core} on central nervous system function (Webborn et al., 2010). Siegel and colleagues elaborated in research with AB athletes, suggesting that ice slurry ingestion may lead to conductive cooling of the facial skin and brain, in turn decreasing central fatigue (Onitsuka et al., 2018). The frontal cortex is related to cognitive function, and therefore related to central fatigue (Onitsuka et al., 2018). Onitsuka et al. (2018) examined this hypothesis and found that ice slurry ingestion significantly reduced both frontal cortex temperature ($P < 0.05$) and rectal temperature ($P < 0.05$). Furthermore, a correlation was found between change in brain temperature and rectal temperature, suggesting that the greater the change in rectal temperature, the greater the change in brain temperature (Onitsuka et al., 2018). These results were attributed to two mechanisms: inflow of cooled carotid blood and conductive cooling of the facial skin and brain (Onitsuka et al., 2018).

A number of studies have investigated the effectiveness of ice slurry ingestion on both physiological measures and athletic performance in the able-bodied population. Siegel and colleagues (2010) examined the difference between 7.5 g/kg of ice slurry (-1°C) and cold water (4°C) ingestion 30 minutes prior to exercise on rectal and skin temperature and run performance in the heat in able-bodied subjects (Siegel et al., 2010). Following ice slurry ingestion, running time was longer (50.2 $\pm$ 8.5 min, P = 0.001) and rectal temperature (T_{rec}) remained lower for the first 30 minutes of exercise (P = 0.001) versus cold water (40.7 $\pm$ 7.2 min) ingestion (Siegel et al., 2010). Similarly, Stevens et al. (2016) found that following ingestion ice slurry 30 minutes prior to repeated three self-paced 5 km run trials, subjects ingesting of 7.5 g/kg of ice demonstrated decreased T_{rec} at the onset of exercise, and T_{rec} remained lower for the first 2 km of running, as compared to a room-temperature control beverage (Stevens et al., 2016). In 2013, Stevens and colleagues conducted unique precooling study with well-trained triathletes (Stevens et al., 2013). Using the classic structure of events during a triathlon, the subjects completed an indoor swim, which served as a precooling method similar to cool water immersion prior to the cycle leg (Stevens et al., 2013). Subjects then ingested 10 g/kg ice slurry between minutes 17-45 of an indoor cycle, before completing a 10 km run (Stevens et al., 2013). The last mouthful of ice slurry was consumed 15 minutes prior to the start of the run leg. Using 10 km run time as a performance measure, run time was decreased by 2.5% (P = 0.03), and subjects reported lower perceived thermal stress at 5 km (P = 0.038) and 9 km (P = 0.039) of the run leg following ice slurry ingestion as compared to the control beverage (Stevens et al., 2013). These findings are in agreement with Yeo et al. (2012), with researchers reporting a 0.6 $\pm$ 1.4% (P = 0.023) improvement in outdoor 10 km run performance following 8 g/kg ice slurry (-1.4°C) ingestion 30 minutes prior to exercise, as compared to a room temperature control beverage, in active individuals (Yeo et al., 2012).

Likewise, Siegel and colleagues (2012) also found that participants were able to exercise longer during a run trial to exhaustion following both cold water immersion (56.8 $\pm$ 5.6 min; *P* = 0.008) and ice slurry ingestion 30 minutes prior to exercise (52.7 $\pm$ 8.4 min; *P* = 0.005), as compared to the control condition, which was ingestion of a warm beverage (46.7 $\pm$ 7.2 min). While subjects ran longer following cold water immersion compared to ice slurry ingestion, researchers concluded that the ~4 minute difference between cold water immersion and ice slurry ingestion was not statistically significant (*P* = 0.355).

However, while a number of studies have observed a positive effect on exercise performance (Stevens et al., 2013; Yeo et al., 2012), the research remains mixed and other studies examining the effectiveness of an ice slurry in able-bodied subjects have found no significant difference in performance (Siegel et al., 2012).

Precooling in Athletes with Spinal Cord Injuries

Conducting research in athletes with spinal cord injuries is difficult due to the highly variable characteristics of the population and relatively small populations in one location. Athletes may respond differently to precooling treatments due to differences in the type of SCI, level of lesion, CNS signaling, and sweat response. To date, only one study has examined ice slurry ingestion as a precooling method in athletes with spinal cord injuries. Instead, precooling research in athletes with SCI has focused on a number of other cooling modalities including cooling garments, water immersion and exposure to cool air.

Cooling Garments

Webborn et al. (2005) and Trbovich et al. (2014) both examined the effects of cooling vests on physiologic outcomes. Webborn and colleagues performed a repeated bout exercise protocol, wherein trained wheelchair tennis and rugby athletes were asked to wear an ice vest either 20 minutes before exercise or during exercise, as compared to a control condition with no cooling measures (Webborn et al., 2005). Following the completion of 14 2-minute bouts of work, it was found that precooling with an ice vest helped to delay an increase in T_{core} until later in the exercise session ($P \leq 0.01$), and resulted in a lower T_{core} at each time point than both during and control conditions ($P \leq 0.01$) (Webborn et al., 2005). Conversely, Trbovich et al. (2014) examined the effect of a cooling vest (15°C) on core temperature during a 60 minute wheelchair basketball or rugby session (Trbovich et al., 2014). While Trbovich and colleagues concluded that the vest was not effective at attenuating an increase in T_{core}, it was noted that hyperthermia (defined as T_{core} max > 37.8°C) was seen in all SCI athletes and 16/19 able-bodied athletes, despite cooling attempts, with quadriplegic athletes demonstrating the greatest increases T_{core} when compared to paraplegic and able-bodied athletes (Trbovich et al., 2014).

Water Immersion

While cooling vests and garments are effective precooling modalities, cold water immersion is considered the "gold standard" (Siegel et al., 2012). Booth and colleagues found that following cold water immersion, able-bodied subjects were able to run longer ($P < 0.05$) and both rectal and skin temperature were decreased by 0.7°C and

5.9°C, respectively ($P < 0.05$), as compared to no cooling (Booth et al., 1997). In athletes with SCI, Goosey-Tolfrey et al. (2008) performed a 60-minute intermittent exercise protocol followed by 10-minutes of passive rest with hand-cooling, before having both able-bodied (AB) and subjects with SCI complete a 1 km time trial (Goosey-Tolfrey et al., 2008). While the performance difference was insignificant between hand-cooling and no cooling, time trial performance was reduced by 20.5 seconds in both AB and SCI subject groups ($P \geq 0.083$) (Goosey-Tolfrey et al., 2008). However, it is important to note that athletes did not enjoy hand cooling, with complaints of numbness, lack of grip, and blistering (Goosey-Tolfrey et al., 2008). This suggests that hand cooling by way of immersion may not be practical for sports in which hand dexterity is important (Goosey-Tolfrey et al., 2008). Forsyth et al. (2016) reported similar findings in subjects with SCI, with cold water immersion eliciting a greater cooling effect ($P < 0.05$) than ice slurry ingestion and site-specific cooling methods during 60 minutes of passive rest (Forsyth et al., 2016).

Artificial Sweat

Water spray bottles are portable and inexpensive tools that are commonly used in the field to help SCI athletes mimic the sweat response experienced by an AB athlete. Pritchett and colleagues (2010) tested the effect of artificial sweat from spray bottles on total work and exercise duration, heat storage, heart rate, and skin, rectal, and esophageal temperature. Wheelchair basketball athletes undertook a repeated-bouts exercise protocol on a cycle ergometer, with seven minutes of work followed by one minute of passive rest, until heat production exceeded heat dissipation. During the passive rest periods, subjects were able to spray water on themselves ad libitum. While there were not any significant differences between the artificial sweat and control conditions on mean total work, exercise duration, heart rate, or skin, rectal or esophageal temperature, researchers noted that the lack of statistical significance should not prevent the use of spray bottles as they don't cause any harm to the athlete or athlete performance (Pritchett et al., 2010). Furthermore, athletes with SCI still commonly use spray bottles in the field setting in efforts to feel more subjectively cool (Trbovich et al., 2014).

Ice Slurry Ingestion

To date, only one study has investigated ice slurry ingestion as a precooling method in athletes with SCI. Forsyth et al. (2016) compared the effects of cold water immersion, ice slurry ingestion (6.8 g/kg), and ice slurry (6.8 g/kg) with the topical application of iced towels to a room temperature, matched volume control beverage as precooling methods in national-level wheelchair basketball athletes (Forsyth et al., 2016). Following a 20 minute precooling period and 60 minutes of passive rest, cold water immersion elicited the greatest reduction in both core and skin temperature, while ice slurry ingestion produced limited physiological impact (Forsyth et al., 2016). However, when ice slurry was combined with the application of iced towels to the legs, torso, and back/arms, T_{core} was reduced at 20 and 30 minutes post-cooling as compared to control (Forsyth et al., 2016). Notably, subjects in all precooling trials reported feeling cooler, measured by a zero (unbearably cold) to eight (unbearably hot) point scale of thermal comfort, compared to the control (Forsyth et al., 2016). Furthermore, despite the limited effect of ice slurry ingestion, Forsyth and colleagues concluded, based on previous research in able-bodied individuals, that ice slurry may be a beneficial precooling method if exercise were to begin immediately after ingestion (Forsyth et al., 2016).

Study Design Considerations

Subjective Ratings of Coolness

Research is limited as to performance benefits of precooling in athletes with SCI. Due to the highly variable nature of the population, it is difficult to quantify work output outside a lab setting. A number of studies are performed within the confines of the laboratory setting, which does not give an accurate picture of "real life" in a sport setting. While a number of studies note little to no effect on T_{core} following cooling, subjective ratings of coolness must also be considered (Pritchett et al., 2010; Trbovich et al., 2014). Goosey-Tolfrey (2008) concluded that as external cooling usually lowers skin temperature, ratings of thermal sensation will be reduced, in turn leading to lessened psychological stress of exercising in the heat (Goosey-Tolfrey et al., 2008). If athletes are reporting to feel "cooler", they may play at a higher intensity for a longer period of time.

Duration and Timing of Cooling

Both internal and external precooling techniques require at least 15 to 60 minutes of exposure to elicit any significant reduction in T_{core} (Griggs and Price, 2014). This is an important consideration when games or matches are played in quick succession, or on an unpredictable schedule. Furthermore, precooling should occur as close to the start of exercise as possible, potentially during the warm-up period (Griggs, Price, and Goosey-Tolfrey, 2015). This way, precooling can provide a benefit well into the exercise period.

Cautions

Taking a cooling medium into the body can promote reduced feelings of thermal strain; however, subjective feelings of "coolness" may mask a critical rise in $T_{core,}$ and lead to increased risk of exercise-induced hyperthermia and other heat-related illness (Trbovich et al., 2014).

Athletes with SCI are at increased risk of autonomic dysreflexia, which can be triggered by a full bladder (Forsyth et al., 2016). Therefore, the total volume of ice slurry should be carefully monitored so as to not overfill the bladder.

Future Research

To date, research is limited in examining the effectiveness of ice slurry ingestion on physiological, perceptual, and performance measures in athletes with SCI. Forsyth et al. (2016) concluded that were exercise to begin immediately after ice slurry ingestion, it may prove an effective precooling method in athletes with SCI. Data has shown that ice slurry is an effective precooling modality in able-bodied athletes (Siegel et al., 2010; Yeo et al., 2012; Stevens et al., 2013), therefore, more research is needed to determine an optimal volume of ice slurry and time of ingestion for athletes with SCI. Research in able-bodied athletes has used various volumes of ice slurry, ranging from 500 g to 1 kg total, or individualized volumes (7.5 g/kg, 8 g/kg, 10 g/kg) (Ross et al., 2011; Siegel et al., 2010; Yeo et al., 2012; Stevens et al., 2013). Thus far, research in athletes with SCI has used 6.8 g/kg of ice slurry, which was well-tolerated by all subjects, although Forsyth et al. concluded that the amount was too small to elicit a significant decline in T_{core}. While increasing the volume of ice slurry is an attractive option, it is cautioned in athletes with SCI due to lower body mass and increased risk of autonomic dysreflexia, which can be triggered by a full bladder (Forsyth et al., 2016). Therefore, continued research is necessary to determine at which volume T_{core} is optimized while minimizing risk to the athlete.

Practical Applications

Athletes with SCI should experiment with various precooling methods to find what works best for them considering the requirements, circumstances, and constraints of training and competition. At present, ice slurry ingestion is a promising method for lowering core temperature prior to exercise, in turn increasing the available margin for metabolic heat production. Ice slurries are practical for match play, as players are not required to wear bulky garments and muscle temperature and hand dexterity are not negatively influenced. Current research supports the consumption of 6.8 g/kg of ice slurry at least 20 minutes prior to exercise to elicit a positive response in core temperature.

Conclusion

In summary, athletes with SCI face unique challenges unlike their AB peers with regard to thermoregulation during exercise. Precooling techniques that aim to reduce core temperature prior to exercise and increase the available temperature margin before T_{core} reaches a critical level can help to offset thermally-induced fatigue during exercise. Cooling garments, water immersion, and artificial sweat are all cooling techniques that have been examined during exercise in athletes with SCI, with mixed results. Given the growing body of evidence in AB athletes that has demonstrated a positive effect on exercise performance, more research is warranted into the effectiveness of ice slurry ingestion as a precooling method in athletes with SCI.

CHAPTER III

METHODS

Participants

Elite wheelchair rugby athletes (n = 13) were recruited from the U.S. National Wheelchair Rugby Team. Males ($\geq$18 years old) with SCI were eligible to participate. Table 1 displays subjects' descriptive characteristics, including classification according to the International Wheelchair Rugby Federation classification system, which is based on an athlete's functional abilities specific to the demands of wheelchair rugby.

This study was approved by the Central Washington University Human Subjects Review Committee. Study participants provided informed consent before participating in this study. Individuals receiving scans of any description (ex. MRI) within the 7-day period following the study, or with history of gastrointestinal surgery, inability to swallow pills, or with a pacemaker were not eligible for participation.

Study Design

Experimental design

A field-based study design was employed to mimic the conditions typical of a wheelchair rugby match, and to assess the practicalities of ice slurry ingestion as a precooling strategy considering the requirements, circumstances, and constraints of training camps and matches (Lee et al., 2015). Data collection took place during two consecutive days in an environmentally controlled gymnasium (21°C). The same procedures were repeated on each day of collection sessions with either the treatment or placebo. Using a counterbalanced design, participants were randomly assigned to a placebo beverage (PLB) or ice slurry (IS) ingestion 20 minutes prior to exercise on day 1 and 2 of training camp. After refraining from exercise for 12 hours prior to the trial, participants began precooling at the same time each day. Baseline measures (T_{core}, heart rate, gastrointestinal comfort, thermal comfort) were collected at the onset of precooling before ice slurry ingestion, followed by 10 and 20 minutes into the precooling period. At the conclusion of precooling, athletes engaged in a game simulation.

Treatment

The IS group received 6.8 g/kg of ice slurry (-2°C) administered in two 3.4 g/kg boluses provided 10 minutes apart to ensure consistent ingestion (Forsyth et al., 2016). Cups were weighed with ice slurry to ensure accuracy of each dose. Ice slurry was made using a 6% carbohydrate (CHO)-electrolyte containing sports drink (Gatorade, PepsiCo, USA) (80 kcal, 22 g CHO, and 0 grams protein per 12 fluid ounces) using a commercial slushie machine (Bunn-O-Matic Corporation, Illinois, USA). Participants were given both a straw and spoon to maximize consumption of ice. The PLB group received an isocaloric 6% carbohydrate-electrolyte (Gatorade, PepsiCo, USA) containing beverage at room temperature (20°C-25°C) at a matched volume and administration.

Exercise protocol

While the work performed was similar for the two days, due to the field-based nature of this study, the amount of work and intensity were not controllable variables.

Employing a self-paced protocol allowed for a more direct assessment of the physiologic response to exercise, which directly correlates with how athletes fare in competition.

After subjects completed precooling, a structured warmup was completed under the direction of the strength coach. The warmup was the same on both days, and progressed in intensity, beginning with low-intensity stretches using an elastic resistance band and building to wheelchair propulsions and sprints (push/pulls) and "tows" in which players propelled themselves down the court while pushing or pulling another teammate and their chair.

Game simulation

Subjects completed a 50 minute game simulation with play divided into 6-minute periods on day 1, while day 2 consisted of a 60 minute game simulation with play divided into 4-minute periods. The exercise pattern of a standard wheelchair rugby match was followed, with intermittent sprints of wheelchair propulsion on a regulation-size indoor basketball court. Normal stoppages occurred for breaks between quarters, substitutions, timeouts, and penalty calls. Official wheelchair rugby rules applied.

Measurements

Physiological measures

Core temperature was recorded every 10 minutes throughout each trial using CorTemp® Ingestible Core Body Temperature Sensors (HQInc., Palmetto, Florida). Core temperature data was wirelessly transmitted to a CorTemp Data Recorder outside the body, as sensors traveled through the digestive tract (Webborn et al., 2005; Griggs et al., 2015). Telemetric sensors were ingested 11 hours before the first trial. Subjects were asked to ingest a second sensor approximately 11 hours before the start of the second trial, if the first sensor passed via bowel movement. The maximum core temperature (T_{core} max) (mean $\pm$ SD) for each subject was determined at the conclusion of the exercise period.

Heart rate was measured every 10 minutes throughout the duration of precooling and exercise with a wearable heart rate monitor (Polar, USA).

Perceptual measures

Perceptual measures were recorded every 10 minutes during the precooling period of each trial. Gastrointestinal comfort and thermal comfort were recorded 30 and 40 minutes into the exercise periods, as well as at the conclusion of the 50 and 60 minute exercise periods on day 1 and 2, respectively. A five-point Likert scale, ranging very uncomfortable to very comfortable, was used to assess gastrointestinal comfort (Forsyth et al., 2016). Thermal comfort was evaluated using a zero (unbearably cold) to eight-point (unbearably hot) scale (Forsyth et al., 2016). Rating of perceived exertion (RPE) was recorded every 10 minutes during the exercise session using the Borg Scale (6-20) (Borg, 1982).

Anthropometric measurements

Weight was recorded via Dual X-Ray absorptiometry (DXA) (Lunar Prodigy Primo, GE Healthcare) scan and this information, along with height, was conveyed to researchers. Scans were undertaken following 12 hours rest in a fasted and hydrated state.

Statistical analysis

Data was analyzed by making probabilistic magnitude based inferences about the true values of the effect of intervention on outcomes. Effect Size (ES) magnitudes were calculated as the difference in means/SD for both groups and were qualified as follows, based on observations of the literature on various precooling methods: small, <0.3; moderate, 0.3-0.6; large, 0.6-0.8; very large, >0.8 (Ross et al., 2011).

Additional analyses were conducted using SPSS software (version 23). The effect of each treatment on core temperature over the 20 minute precooling period and the 50-60 minute exercise period were compared using a repeated measures ANOVA (treatment x time). Independent t-tests were used to identify interactions between time and treatment for the perceptual rating of thermal and GI comfort at the mid (30-40 minutes) and end-points (50-60 minutes) of exercise, as well as for RPE and heart rate every 10 minutes during the exercise period. Data are reported as mean +/- standard deviation (SD) and results were considered significant at $P \leq 0.05$.

CHAPTER IV

RESULTS

Descriptive and SCI characteristics are presented in Table 1. N = 12 subjects completed data collection on both days. One subject was excluded, as the telemetric pill was passed after the completion of day 1, and a second pill was not ingested. Given that the amount of work performed by the subjects differed between days, results are presented separately for day 1 and 2.

Table 1. Participant descriptive characteristics (n = 13)

Participant	**Age (Years)**	**Body Mass (kg)**	**Injury**	**Injury Level**	**Years Since Injury**	**Classification**
1	26	46.8	Congenital	-	-	2.0
2	25	73.6	I	C6-C7	3	2.5
3	32	90.9	I	C6-C7	13	2.0
4	33	54.5	I	C6-C7	19	1.0
5	38	95.4	I	C7	15	2.0
6	34	53.6	I	C5-C6	15	1.0
7	45	84.1	I	L1-L2, C6-C7	24	2.5
8	27	56.4	I	C5-C6	14	0.5
9	29	74.1	I	C5	13	1.5
10	37	72.7	I C	C2, T9-T10	11	2.5
11	29	63.6	I	C5	9	1.0
12	35	70.4	I	C7	20	2.0
13	27	50	I	C6	12	1.0
Mean (SD)	**32.1 (5.8)**	**68.2 (15.7)**			**14 (5.4)**	

Note: I = incomplete; C = complete

Core temperature

The changes in T_{core} over time for both days 1 and 2 are presented in Figures 1 and 2, respectively. T_{core} for each condition and trial are presented in Table 2. Analysis of T_{core} over time revealed IS had a large effect at the midpoint of exercise (minute 30) (ES = 0.73) and a moderate effect at the end of exercise (minute 50) (ES = 0.51) on day 1. However, a repeated measures ANOVA displayed no significant interaction over time for IS (P = 0.13), but there was for PLB (P = 0.02). Pairwise comparison revealed interactions between baseline and minute 50 in the PLB group (P = 0.04), indicating T_{core} was 1.30°C ± 0.24°C higher at minute 50 as compared to baseline. On day 2, IS ingestion had a very large effect on T_{core} at the midpoint of exercise (minute 40) (ES = 1.17) and a large effect at the end of exercise (minute 60) (ES = 0.63). A repeated measures ANOVA revealed a significant interaction over time for IS (P = 0.01), with pairwise comparisons showing interactions between minutes 10 and 60 of exercise. No significant interactions were observed in the PLB group on day 2. The increase in T_{core} from baseline to the end of precooling was greater on both days 1 (+1.18 ± 0.55°C) and 2 (+0.8 ± 0.58°C) for PLB as compared to IS (+0.97 ± 1.28°C and +0.25 ± 0.53°C for day 1 and 2, respectively). Conversely, from the end of precooling until the end of exercise, the increase in T_{core} was greater for IS (+0.99 ± 0.83°C, and +0.72 ± 0.51°C for day 1 and 2, respectively) compared to PLB (+0.42 ± 0.55°C, and +0.33 ± 0.68°C).

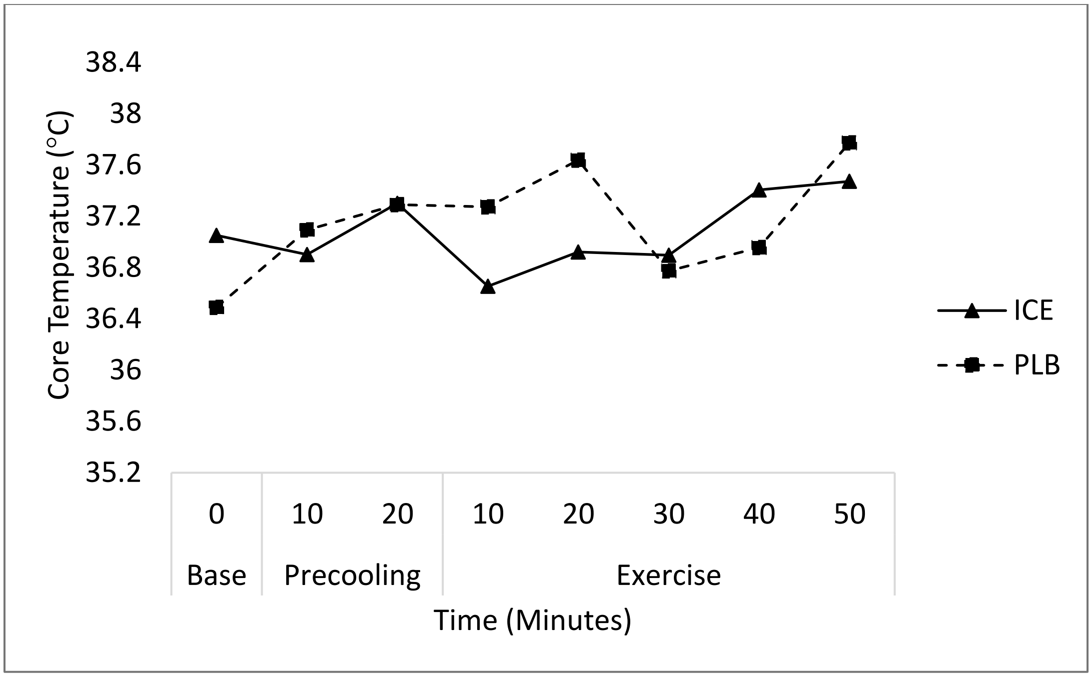

Figure 1. Changes in T_{core} (°C) over time during the precooling and exercise periods on trial day 1.

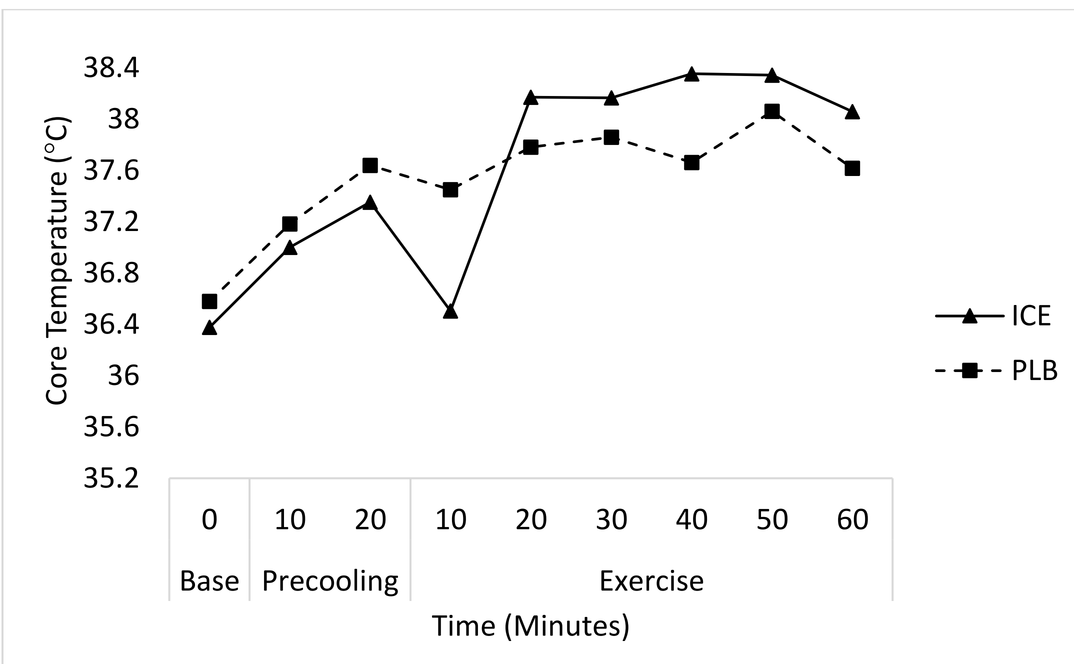

Figure 2. Changes in T_{core} (°C) over time during the precooling and exercise periods on trial day 2.

Table 2. T_{core} (°C) for all conditions and changes in T_{core} (°C) over time.

Day	Condition	Baseline (0 min)	End of Precooling (20 min)	**Delta (0→20 min)**	End of Exercise (70 min)	**Delta (20→70/80 min)**	**Delta (0→70/80 min)**
1	**IS**	36.38 (1.65)	37.33 (0.92)	**+0.97 (1.28)**	38.34 (0.75)	**+0.99 (0.83)**	**+1.97 (1.20)**
	PLB	36.46 (0.62)	37.64 (0.48)	**+1.18 (0.55)**	38.06 (0.62)	**+0.42 (0.55)**	**+1.59 (0.62)**
2	**IS**	37.05 (0.44)	37.3 (0.62)	**+0.25 (0.53)**	38.06 (0.39)	**+0.76 (0.51)**	**+1.01 (0.42)**
	PLB	36.49 (0.72)	37.29 (0.45)	**+0.8 (0.58)**	37.61 (0.91)	**+0.33 (0.68)**	**+1.13 (0.81)**

Heart rate

No meaningful effects were observed in heart rate between time and treatment for either condition during day 1 or 2.

Thermal comfort

The rating of thermal comfort for both days 1 and 2 are presented in Figures 3 and 4, respectively. Analysis of perceptual rating of thermal comfort over time revealed that IS had a very large effect at the midpoint of exercise (minutes 30 and 40, respectively) on days 1 (ES = 1.30) and 2 (ES = 1.47). Independent samples T-tests revealed significant differences between IS and PLB at the midpoint of exercise on both day 1 (P = 0.04) and 2 (P = 0.05). Further, following IS ingestion, subjects rated thermal comfort 1.51 and 1.43 points lower for day 1 and 2, respectively, at the mid-point of exercise as compared to PLB. At the end of exercise, IS ingestion had a very large effect on day 1 (ES = 0.79) and a moderate effect on day 2 (ES = 0.41). An independent samples T-tests revealed no significant differences between treatments (PLB, IS) for either day at the end of exercise.

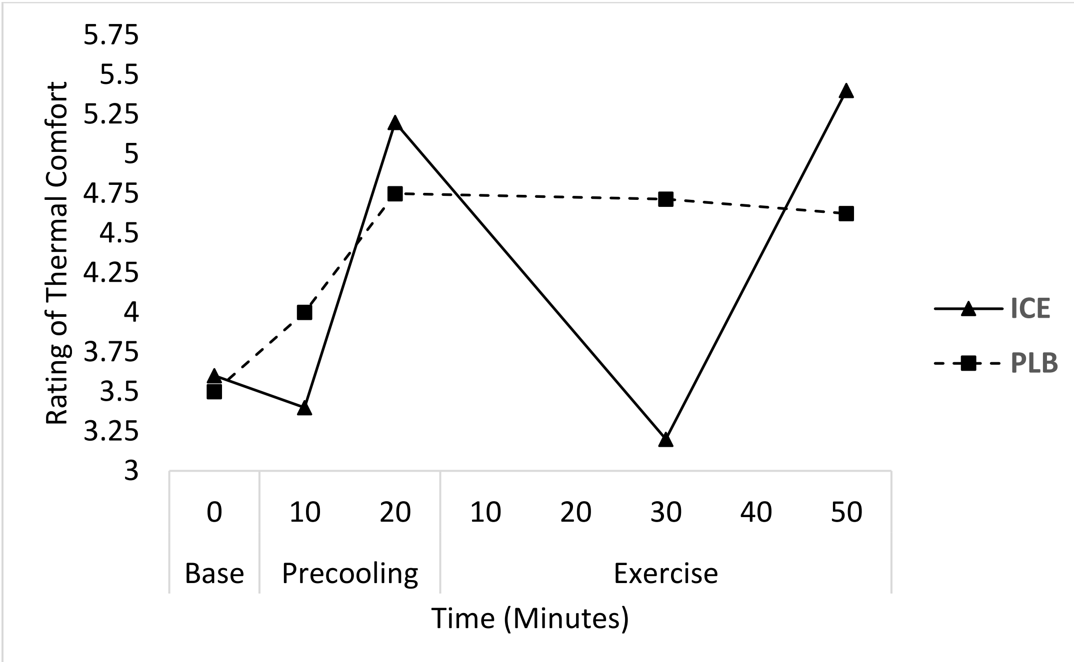

Figure 3. Change in rating of thermal comfort over time on trial day 1.

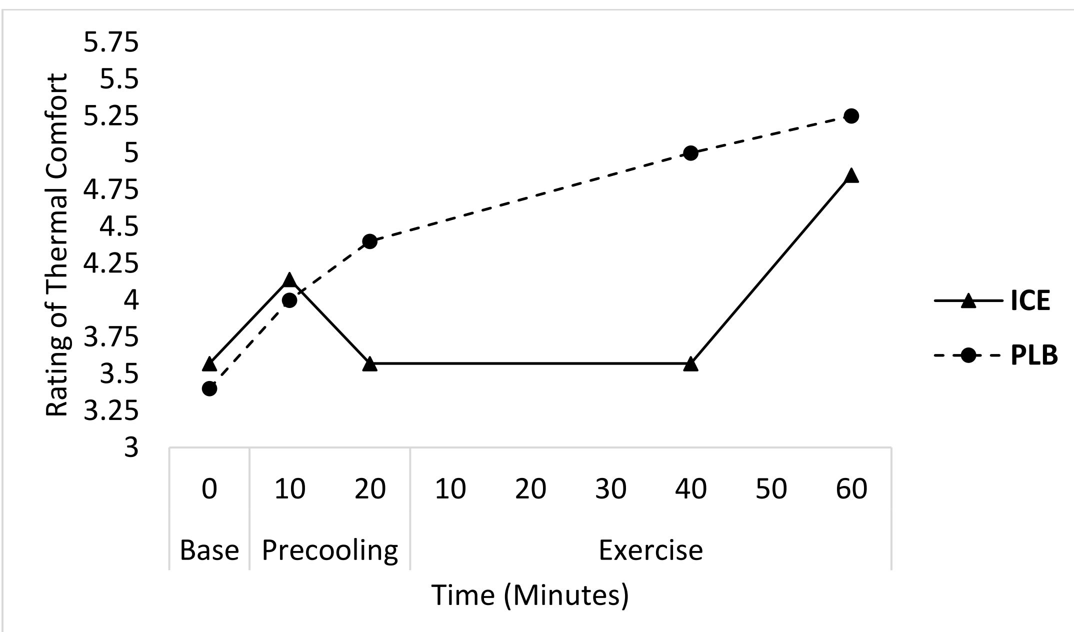

Figure 4. Change in rating of thermal comfort over time on trial day 2.

Gastrointestinal (GI) comfort

No significant effects were observed in the subjective rating of gastrointestinal (GI) comfort between time and treatment for either condition. For each measurement during precooling (minutes 10, 20) and exercise (minute 30 and 50 on day 1, minute 40 and 60 on day 2), mean GI comfort ratings were within a 'comfortable' range (3-5).

Rating of perceived exertion

No meaningful effects were observed at any time point for either condition in the subjective rating of perceived exertion (RPE) for day 1 or 2.

CHAPTER V

DISCUSSION

The purpose of this study was to investigate the effects of pre-exercise ice slurry ingestion as a practical and affordable precooling strategy on physiological and perceptual measures during an on-court match simulation session in elite wheelchair rugby players. The primary findings suggest that ice slurry ingestion before exercise elicits a positive response on T_{core} at the end of precooling through the first ~30 minutes of exercise. For both trial days, the increase in T_{core} was greater for PLB than IS from baseline until the end of precooling. Further, following IS ingestion, subjects reported feeling cooler through the first half of exercise than PLB. Therefore, the current study suggests that IS ingestion is an effective precooling method in elite wheelchair rugby players during match simulation held in a moderate environment.

These findings are consistent with previous research in AB populations where Byrne et al. (2011) noted following cold fluid infusion, intragastric temperature was not similar to the control condition until minute 15 of exercise, signifying a possible long-lasting reduction in intragastric temperature following cold fluid, including ice, intake (Byrne et al., 2011). This is supported by another study which showed that following IS ingestion, rectal temperature was lower at the onset of exercise and remained lower for the first 2 km of a 5 km run trial compared to a room temperature control beverage (Stevens et al., 2016). Similar to our findings where T_{core} remained lower with IS until minutes 20 and 40 of exercise on day 1 and 2, Forsyth et al. (2016) reported that in athletes with SCI, T_{core} remained lower at 40 and 50 minutes into a period of passive rest after subjects precooled with IS and iced towels as compared to no cooling (Forsyth et al., 2016). Compared to AB individuals, research suggests that when cooled at rest, tetraplegic individuals demonstrate greater decreases in T_{core} due to the lack of sympathetically-induced vasoconstriction and an inability to generate large amounts of metabolic heat from shivering as a result of paralysis (Webborn et al., 2010). Therefore, the findings of the current study suggest that IS ingestion generates a pronounced decrease in T_{core} during the precooling period.

Conversely, the IS group demonstrated a greater change in T_{core} from the onset to the end of the exercise period compared to PLB. Yeo et al. (2012) reported similar findings in AB populations, wherein despite similar increases in gastrointestinal temperature (T_{gi}) throughout precooling and warm-up, subjects who ingested IS 30 minutes before engaging in a 10 km run trial finished the exercise period with a higher T_{gi} compared to subjects who consumed a room temperature control beverage (Yeo et al., 2012). This may be due to a number of factors. Siegel et al. (2012) proposed that a higher T_{core} following IS ingestion could be due to the stimulation of internal thermoreceptors, which may have the potential to convey a “false” sense of the body’s thermal state, and in turn elicit the perception of exercise as being easier at a given thermal load (Siegel et al., 2012). For athletic performance, this sensation may be advantageous, as players perceive less thermal stress, in turn playing harder and longer. However, without a true sense of the body’s thermal state, hyperthermic conditions may be masked, putting the athlete in potential danger. This should be noted in athletes with SCI as tetraplegic individuals possess a lesser amount of sensate skin and afferent input regarding their thermal state (Griggs et al., 2015). In the present study, total work was not measured, therefore, it is not possible to determine if the IS group actually performed more work. However, approximately half of subjects (58.3% on day 1 and 50% on day 2) in both conditions, experienced exercise-induced hyperthermia (EIH), defined by the American College of Sports Medicine (ACSM) as T_{core} > 37.8°C-38.3°C (Trbovich et al., 2014). This data is presented in Table 3. Despite this, no participant terminated participation early or demonstrated symptoms of heat exhaustion (T_{core} < 40°C) or heat stroke (T_{core} > 40°C) by ACSM criteria.

Table 3. T_{core} max (°C) at the conclusion of exercise. Percent (n) of subjects during each condition who had a T_{core} max greater than 37.8°C, 38.3°C, and 38.9°C cutoff values.

Day	Condition	Mean (*SD*)	%T_{core} max			
			<37.8°C	>37.8°C	>38.3°C	>38.9°C
1	IS	38.34 (0.75)	20% (n = 1)	60% (n = 3)		20% (n = 1)
	PLB	37.99 (0.62)	14.2% (n = 1)	57.1% (n = 4)	28.6% (n = 2)	
2	IS	38.06 (0.39)	28.6% (n = 2)	42.9% (n = 3)	28.6% (n = 2)	
	PLB	37.62 (0.91)	40% (n = 2)	60% (n = 3)		

Values are displayed as Mean (SD).

Stevens et al. (2016) noted that even a 0.4-0.5°C decrease in T_{core}, IS ingestion is associated with a transient decrease in the perception of thermal comfort at the beginning of exercise (Stevens et al., 2016). In support of this, despite the greater increase in T_{core} observed in the IS group throughout exercise, subjects in the IS group reporting feeling cooler at the end of exercise on both days compared to PLB. Recent research has demonstrated that perception of thermal sensation is an important contributor to self-selected exercise intensity, suggesting that if players are feeling cooler, exercise intensity increases (Stevens et al., 2016). In the current study, RPE and HR were assessed at 10 minute intervals during the exercise period, and no meaningful differences were observed for either variable in either condition at any time point. However, given the intermittent nature of wheelchair rugby, and the field-based setting of this study, it is difficult to conclude whether subjects in one condition were playing harder than the other. Normal stoppages and substitutions were allowed during exercise so it was possible that subjects were resting when measurements were taken.

Finally, the volume and timing of ice slurry ingestion were well-tolerated, with the biggest complaint being "brain freeze". From baseline throughout precooling and the entirety of exercise, subjects in both groups on both days rated gastrointestinal comfort within a "comfortable" range (3-5). Future research should examine the timing of ingestion, including the viability and effectiveness of ad libitum IS ingestion during exercise and rest periods, such as half-time during a match. Furthermore, most studies examining the effectiveness of precooling methods in SCI populations fail to employ a standard measure of performance, making it difficult to assess whether there is a clear performance benefit associated with any precooling method (Griggs et al., 2015). However, it should be noted that accounting for the amount of work performed is more practical in the laboratory-setting, and those results may not be transferrable to "real life" situations.

Limitations

The primary limitation of this study is that the amount of work performed on day 1 and 2 were likely not identical, given that intensity is not a controllable variable during match play. Furthermore, due to the intermittent nature of a typical wheelchair rugby match, it is reasonable to assume that the work performed from one match to another is inconsistent. However, the nature of the study has high external validity given the field-based design. Our results may be more practical in mimicking the conditions that athletes experience while participating in training camps and match play, where intensity and duration of work varies from each day. Many studies are performed in a laboratory setting, seeking to control variables such as intensity, but may lack external validity. Further, air velocity plays a significant role in the rate of heat storage, and is often unaccounted for in laboratory-controlled studies. The study results demonstrate that ice slurry ingestion is a practical and effective precooling strategy, especially when considering the requirements, circumstances, and constraints of training camps and matches. Lack of statistical significance should not preclude ice slurry use, as we did not note any harm or adverse effects to athlete health or athletic performance.

Practical Applications

Increased core temperature is commonly cited as one of the main reasons for decreased athletic performance, especially in endurance events (Gonzalez-Alonso and

Teller, 1999). Research shows that as T_{core} rises, athletes will experience decreased endurance performance and capacity, in addition to a faster onset of fatigue and decreased time to exhaustion (Goosey-Tolfrey et al., 2008; Siegel et al., 2010). Our research suggests that, when ingested 20 minutes before exercise, IS can be an effective method to both lower T_{core} and delay the time before reaching a critically high T_{core}. Additionally, our findings suggest IS ingestion is a practical precooling method as it did not compromise athlete comfort, or interrupt the sequence of pre-event or half-time routines. In competition settings, it is practical to expect that athletes will have a warm-up period that increases muscle temperature, which may diminish the effects of external cooling methods. Athletes did not voice concerns of IS ingestion negatively impacting active muscle tissue or impairing hand dexterity necessary for wheelchair propulsion, as is sometimes experienced with external cooling methods like cooling vests or hand/foot cooling. Lastly, although the volume of ice slurry in the present study was well-tolerated, athletes with SCI should be careful to empty the bladder before ingestion as to not trigger autonomic dysreflexia.

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