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Ice Slurry and Cold Drink Reduces Exercise Induced Physiological Strain in the Heat

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ICE SLURRY AND COLD DRINK REDUCES EXERCISE INDUCED

PHYSIOLOGICAL STRAIN IN THE HEAT

By

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Ice slurry and cold drink reduces exercise induced physiological strain in the heat

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Purpose: To determine the effects of an ice slurry beverage on heat strain and thermoregulatory responses during prolonged exercise in the heat. **Methods:** Twenty males consumed slurry (ICE, -1.4 ± 0.2 °C), cold drink (COLD, -0.7 ± 0.2 °C), or room temperature drink (RT, 21.5 ± 1.0 °C), while walking at 50% of VO_{2max} for 90 minutes in the heat (43.3 °C and 40% humidity). Heart rate (HR), core temperature (T_c), skin temperature (T_s), physiological strain index (PSI), sweat rate, and ratings of perceived exertion (RPE) were recorded. **Results:** T_c was lower at minutes 30, 60, and 90 during ICE (37.8 ± 0.1 °C, 38.3 ± 0.1 °C, 38.5 ± 0.1 °C) and COLD (37.8 ± 0.1 °C, 38.3 ± 0.1 °C, 38.7 ± 0.1 °C) vs. RT (37.9 ± 0.1 °C, 38.6 ± 0.1 °C, 39.2 ± 0.1 °C). HR was lower during ICE (138 ± 3) vs. RT (145 ± 3). PSI was lower in ICE at minutes 30, 60, and 90 (8.0 ± 0.3, 9.2 ± 0.4, 10.0 ± 0.4) and minutes 60 and 90 (9.2 ± 0.5, 10.0 ± 0.7) for the COLD compared to RT (8.4 ± 0.3, 10.3 ± 0.4, 11.5 ± 0.5). T_s and RPE were lower in the COLD vs. RT during the latter portion of the exercise. Sweat rate was lower during the ICE (11.81 ± 0.48 $g \cdot m^{-2} \cdot min^{-1}$) compared to the COLD (12.16 ± 0.51 $g \cdot m^{-2} \cdot min^{-1}$) and RT (12.95 ± 0.56 $g \cdot m^{-2} \cdot min^{-1}$). **Conclusion:** Ice slurry or a cold drink, reduces physiological strain during exercise in the heat and may act to decrease the acute risk for heat related injury.
Key Words: THERMOREGULATION, CORE TEMPERATURE, HEAT RELATED INJURY, ACCLIMATION, INTERNAL COOLING

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Chapter One: Introduction

Introduction

Paragraph 1 Athletes, military combatants, and occupational workers who regularly perform in hot environments, experience high core temperatures and physiological strain during work, competitions, and practices (2-4, 10, 11, 14, 18, 21, 32, 33, 36). Heat stress is manifested when the body is exposed to hot and humid environments causing perceived discomfort (6), which can lead to heat strain and any of the following: cardiovascular strain, central nervous system dysfunction, volitional fatigue, hyperthermia, heat exhaustion, heat stroke, or possibly death (6, 9, 10, 12). In addition to environmental conditions, the type of clothing worn and physical activity can influence the amount of heat stress induced, affecting core temperature, overall physiological strain, and increasing the risk for heat related injury (HRI) (9, 30, 38).

Paragraph 2 Previous research has demonstrated that core temperature increases more rapidly and is associated with volitional fatigue during exercise in the heat (8, 12, 15, 26, 29). Additionally, when core temperature exceeds 39°C, impairments in performance are typically observed (8, 15, 17, 23, 26, 27, 31). However, if the rise in core temperature or heart rate is mitigated, then heat strain will be reduced, thereby attenuating the overall physiological strain and subsequent HRI risk (7, 24).

Paragraph 3 To reduce heat strain during exertion in hot environments, pre-cooling techniques such as ingestion of cold water, wearing ice vests, and submersion in cold water have been utilized to lower pre-exercise core temperature. Such methods result in improved performance and extended exercise tolerance (1, 5, 16, 19, 28, 29, 34). In addition, ingestion of an ice slurry beverage at regular intervals has been demonstrated as a viable pre-cooling technique to reduce pre-exercise core temperature (34). It has been established that more energy is required to bring a volume of saline ice slurry from 0 °C to 34 °C than to bring the same volume of liquid saline from 0 °C to 34 °C (39). This finding can be attributed to the theory of enthalpy of fusion, which demonstrates that it takes 344 $kJ \cdot kg^{-1}$ of energy to melt ice to liquid at 0 °C (40). The additional heat needed to melt ice to water could create a "heat sink" if ingested in a physiological system. During exercise this might allow metabolic heat to be transferred in the phase change of ice to water, possibly reducing core temperature beyond the capabilities of cold water at the same temperature (34).

Problem

Although ice slurry has been used as a means of pre-cooling (47), its use during prolonged exercise in the heat modifying overall physiological strain and thermoregulation has not been addressed. Thus, it is not known if the ingestion of an ice slurry would provide a better cooling effect compared to cold fluids of the same temperature.

Purpose

The purpose of this study was to determine the effects of an ice slurry beverage on heat strain and thermoregulatory response during prolonged exercise in the heat.

Null Hypotheses

1. Type of beverage will have no effect on core temperature during exercise in the heat.
2. Type of beverage will have no effect on heart rate during exercise in the heat.
3. Type of beverage will have no effect on RPE during exercise in the heat
4. Type of beverage will have no effect on skin temperature during exercise in the heat.
5. Type of beverage will have no effect on physiological strain index during exercise in the heat.

6. Type of beverage will have no effect on sweat rates during exercise in the heat.

Significance and Rationale

The findings of this research study have implications on persons who perform in hot conditions that experience strain. If ice slurry ingestion is found to be a significant way of reducing heat strain induced upon the human body, then practical guidelines can be established encouraging consumption of ice slurry in the field to reduce heat strain and thereby diminish the risk of a heat related incidents.

Limitations

1. Outside environmental conditions cannot be controlled. Therefore, we cannot ensure that weather patterns will produce temperatures consistent over the three-week data collection period, which can influence heat acclimatization and consequently core temperature.

2. Participants' lifestyle between the trials cannot be controlled. In order to better control physical activity levels, a dietary and physical activity recall for the day prior the exercise trial will be recorded and repeated.

3. Human error can occur with the use of any instrumentation. To limit the occurrence of error, all researchers will be trained and equipment will be carefully calibrated.

4. Participants will not be randomly sampled; however, they will be recruited by convenience. However, random ordering of treatments will be utilized.

Delimitations

1. All participants in this study will be males who are recreationally active. Due to the effects of the menstrual cycle on core temperature, females will be excluded from this study.

Definition of Terms

Heat Strain: heat stress manifesting itself as either physiological consequences, such as if core temperature and heart rate are affected (7), or perceptual consequences, such as if perceived exertion is affected (52). Heat strain can cause any of the following: cardiovascular strain, central nervous system dysfunction, volitional fatigue, hyperthermia, heat exhaustion, heat stroke, or possible death (7, 11, 13, 17).

Physiological strain index (PSI): is a non-invasive model that calculates the strain induced upon the body utilizing core temperature (or skin temperature) and heart rate. PSI is calculated on a scale from 0-10 and can classify individuals at risk (values > 7.5) for heat related incidents based upon the PSI value (8, 33). Physiological strain index (PSI) was be determined by the equation developed by Moran et al. (33) using T_c and HR data. Where $T_{core(0)}$ and HR_0 were the initial core temperature and heart rate as measured at the commencement of exercise.

$$PSI = 5\,(T_{core(t)} - T_{core(0)}) * (39.5 - T_{core(0)})^{-1} + 5\,(HR_t - HR_0) * (180 - HR_0)^{-1}$$

Recreationally active individuals: individuals who exercise on a regular basis but who may work indoor during the workweek and/or exercise outdoors on a varying basis throughout the week.

VO_2 max: the maximal amount of oxygen an individual's metabolism can utilize during a graded maximal exercise test.

Sweat rate: The amount of sweat produced by the body per unit of time relative to body surface area expressed in "$g \cdot m^{-2} \cdot min^{-1}$".

Ice slurry: an icy beverage made with a mixture of ice and water.

Chapter Two: Review of Literature

Fatigue in Hot Environments

It is well established that hot environments can impair exercise performance (15, 17, 39). Parkin et al. (39) studied the effects of ambient temperature on skeletal muscle metabolism during fatiguing submaximal exercise. Their study focused on the hypothesis that performance impairment in the heat could possibly be due to limited carbohydrate availability. In order to test this idea, subjects cycled at 70% VO_2 max on three separate occasions in three different ambient temperatures (3, 20, and 40°C). Time to exhaustion was measured as well as muscle glycogen content both before and after the performance trials via muscle biopsies. Time to exhaustion was shortest in the hot environment and longest in the colder trials. Consequently, the researchers concluded that fatigue occurs more rapidly in a hot climate and it is not related to carbohydrate availability.

To further elucidate heat's deleterious effects on performance and inducing fatigue, Galloway et al. (17) conducted a research study determining the effects of four different ambient temperatures on cycling performance. Subjects rode at 70% VO_2 max at ambient temperatures of 3.6, 10.5, 20.6, and 30.5°C with 70% humidity. The researchers found that time to exhaustion was the longest at 10.5°C and shortest at 30.5°C. Additionally, core temperature was significantly higher during the hot ambient temperature trial in relation to the colder trials. Thus, these findings further demonstrate that hot and humid climates negatively affect exercise capacity.

Core Temperature in the Heat

Researchers have demonstrated that core temperature rises during exercise in hot environments and is associated with fatigue during exercise in the heat (9, 17, 20, 36, 39, 40). Gonzolas-

Alonso et al. (20) studied the influence of initial body temperature on time to exhaustion while cycling in the heat (40°C). In order to determine if pre-exercising core temperature affected performance, subjects performed three cycling performance trials at 60% VO_2 max in the heat. In order to control the subject's pre-exercise core temperature (either 36, 37, or 38°C), the subjects were submerged in water at three different temperatures depending on the trial for 30 minutes. The researchers discovered that regardless of the trial, volitional fatigue occurred around 40°C and that starting core temperature was inversely related to time to exhaustion. Therefore, it was concluded that high internal body temperature, typically 39°C, is associated with fatigue during exercise in the heat, which has been established by other studies (9, 25, 32, 36, 37, 44).

Heat Stress, Strain, and PSI

Heat stress is manifested when the body is exposed to hot and/or humid environments, causing perceived discomfort (7). In addition to environmental conditions, the type of clothing worn and physical activity can also influence the amount of heat stress induced. (11, 42, 52). Sawka et al. (42) further explains that uncompensable heat stress occurs when the evaporative cooling requirements exceed the ambient environment's cooling capacity. Heat stress may lead to heat strain if the stress has physiological consequences, such as if core temperature and heart rate are affected by heat stress (7), or perceptual consequences, such as if perceived exertion is affected by heat stress (52). Heat strain can lead to any of the following: cardiovascular strain, central nervous system dysfunction, volitional fatigue, hyperthermia, heat exhaustion, heat stroke, or possible death (7, 11, 13, 17).

In order to quantify heat strain induced by the body, Moran et al. (33) developed a model using rectal temperature and heart rate as variables to calculate the physiological strain index (PSI), which is on a scale from 0-10. Buller et al. (8) adapted this model as well as five other PSI models to develop a more practical way of determining PSI using chest skin temperature and heart rate. Furthermore, the research group was able to classify workers with PSI values ≥ 7.5 as "at risk" for complications related from heat strain. Thus a lower heart rate and/or skin temperature leads to a lower heat strain on the body, thereby reducing the chance of a heat related illness.

Thermoregulation

More than 75% of the energy produced by skeletal muscle is lost as heat (55). Thus, the human body must have a sufficient system of dissipating heat in order to prevent hyperthermia. Fortunately, there are a few physiological mechanisms in place that aid the transfer of metabolic heat to the environment. These mechanisms aid in preventing the rise of core body temperature from reaching critical levels during times of high metabolic heat production which can be exacerbated from either hot environmental conditions, during times of intense physical activity, or both (55).

Redistribution of Blood Flow

The modulation of skin blood flow is an effective means of regulating core temperature. During times of hyperthermia, vasodilation of cutaneous blood vessels occurs. In response, more blood is shunted from the core to the skin, thus dissipating excess metabolic heat to the environment (55). When fully dilated, cutaneous blood flow rates can reach 8 L/min (24). However, during times of heavy exercise, dehydration, or when core temperature exceeds 38°C, blood flow to the skin is reduced to better maintain demands of the skeletal muscle. Consequently, the body's ability to transfer heat from the core, to the skin, then to the environment is reduced during heavy exercise (23, 24).

Sweat Response

When ambient temperature exceeds 36°C, the body is unable to dissipate heat via convection and radiation, thereby relying on the evaporation of sweat as the predominant means of heat dissipation (55). However, sweating is only an effective means of heat dissipation when evaporation can effectively take place such as when ambient humidity is low. When 1 mL of sweat is evaporated, 2.43 kJ of heat is released, thus making the sweating mechanism a very efficient way of dissipating heat. However, when humidity is high, then evaporation cannot effectively take place; therefore, resulting in very little cooling (10). In order to meet the body's demands of cooling, athletes commonly maintain sweat rates of 1.0 – 2.5 L/hr; indeed, values greater than 3.5 L/hr during times of high ambient temperatures and intense exercise have been demonstrated (43, 55).

Cold Fluids

Cold fluid consumption has shown to have mixed effects during exercise performance in the heat. Mundel et al. (35) observed the effects of different drink temperatures on cycling performance in the heat. The eight cyclists rode to exhaustion at 65% of their Watts max in a 34 °C and 28% humidity environmental chamber on two occasions while drinking cold water (4 °C) or warm water (19 °C). An 11% improvement in time to exhaustion was found during the cold drink trial and a lower heart rate and core temperature. However, subjects drank more (1.3 ± 0.3 L/hr) in the cold drink trial compared to the warm drink trial (1.0 ± 0.2 L/hr). The researchers concluded that the cold drinks improved performance; however it is possible that the amount of fluids consumed had a more profound impact on endurance performance.

Lee et al. (28) in a similar study took eight men and cycled them at 50% of VO_2 max for 90 minutes in an environmental chamber (25 °C and 60% humidity) on three separate occasions. At 90 minutes the cyclists begun a performance trial and rode to exhaustion at 95% VO_2 max. This occurred three times with different drinks administered in 400 mL aliquots at four time periods throughout the exercise trial at three temperatures: cold (10 °C), warm (37 °C), or hot (50 °C). The temperature of the drinks showed no effect on time to exhaustion, core temperature, or heart rate. Therefore, the researchers concluded that drink temperature had no effect on thermoregulatory function and cycling performance.

In contrast, Lee et al. (29) showed a reduction in core temperature during a cycling performance protocol at 66% $VO_{2\ peak}$ when participants precooled by drinking cool water (4 °C) 30 minutes before (300 mL every 10 minutes) and during the performance trial (100 mL every 10 minutes). However, it was not possible to discern if the observed reduction in T_c during the exercise trial was attributed to precooling and a lower initial T_c or from the continued ingestion of cold drinks throughout the exercise trial. Thus, it is still apparent that the effects of cold fluid ingestion during exercise are still not clear.

Pre-Cooling

Pre-cooling has been developed to combat the decline in performance and heat stress induced when exercising in hot and humid conditions. Pre-cooling is a method used to lower core body temperature before a bout of exercise, which increases the body's capacity to tolerate heat, increasing time to fatigue. This concept of increasing heat capacity allows the body to perform more work before a limiting core temperature is reached (41).

There are numerous methods that have been developed to lower core body temperature before bouts of exercise. One simple method is exposure to cold air (21, 27, 38). Lee and Haymes (27) exposed 14 runners to normothermic (24°C) or a hypothermic (5°C) conditions for 30 minutes followed by 10 minutes of rest at 24°C. Runners then ran at 82% VO_2 max in either the normothermic or hypothermic condition until volitional exhaustion. During the hypothermia condition, the subjects started exercise with a 0.37 °C reduction in core temperature resulting in a 121% improvement in time to exhaustion. Cold air exposure was concluded to be a successful method of pre-cooling resulting in increased heat tolerance and performance, which was found in other studies (21, 38).

Cold water immersion has been another popular method used to pre-cool (5, 22). Booth et al. (5) conducted a pre-cooling study and immersed eight subjects in 23-24°C water for 30 minutes in a hot and humid climate prior to the completion of a 30 minute performance test. In the pre-cooling trial, subjects' pre-exercise core temperature was reduced by 0.7°C resulting in a 4% improvement in the distance traveled.

Other pre-cooling techniques have also been studied and have been shown to successfully improve performance and lower core body temperature such as wearing ice vests before exercise (1, 12), drinking cold water (29), and ingesting an ice slurry beverage (47).

Ice Slurry

The theory behind ice slurries, a mixture of ice and water, is based on the enthalpy of fusion which states that a large transfer of heat is needed for ice to undergo a phase change to water relative to the amount of heat required to raise the temperature of water alone (47). Vanden Hoek et al. (53) demonstrated that a mixture of 1000ml of half ice and half liquid saline required 80 kcal of energy to raise the temperature from 0 to 34°C, whereas 1000 mL of only liquid saline required 34 kcal to raise the temperature from 0 to 34°C. In the same study it was also shown that an intravenous injection of ice slurry decreased brain temperature by 5.3°C relative to only 3.4°C when the same temperature (0-1°C) saline was intravenously infused in swine.

Based on enthalpy of fusion, Siegel et al. (47) hypothesized that ingestion of ice slurry before exercise would create a "heat sink", which would allow more metabolic heat to be transferred in the conversion of ice to water, resulting in a lowered core temperature. Therefore, he conducted a random and counterbalanced study with two trials. The 10 males that participated in the study either ingested 7.5 g/kg of ice slurry (-1 - 0°C) or cold water (4°C) in a 30-minute period before running to exhaustion in a hot and humid environment (34.0°C and 54.9% relative humidity). Time to exhaustion, pre and post-exercise core temperatures, skin temperature, heart rate, sweat rate, perceived exertion, and thermal sensation was measured. Time to exhaustion was greater in the ice slurry trial versus the cold water (50.2 minutes vs 40.7 minutes) and perceived exertion as well as thermal sensation was lower in the ice slurry trial versus the cold water trial. After ice slurry ingestion and before exercise core temperature was reduced by 0.66°C relative to only 0.25°C after cold water ingestion. Thus, it was concluded that an ice slurry beverage was an effective pre-cooling modality compared to water. However, both drinks were not the same temperature so it can't be concluded that ice slurry acted as a greater heat sink compared to the same temperature liquid.

Heat Stress in Populations

The environments of preseason football practices are generally very hot and humid occurring in late summer during the hottest part of the year. In the period from 1995 to 2001 there were 21 deaths from complications of heat stroke in young football players. Consequently, core temperatures can routinely exceed 39°C (4, 19). Additionally, other athletes such as soccer players (2, 14, 46), distance runners (30), and triathletes (26, 45) are capable of reaching high core temperatures during competitions. Occupations such as wildland firefighters (13) and military personal (3, 50) are also susceptible to heat stress and heat stroke.

Cuddy and Ruby (13) published a case study on a wildland firefighter who collapsed due to heat exhaustion during fire suppression. The 24 year old was arduously working in very high ambient heat (average temperature 44.6°C, maximum temperature 59.7°C) for seven hours. Despite drinking large amounts of fluids, his core temperature reached 40.1°C and he ultimately collapsed due to heat exhaustion. The researchers concluded that despite generous amounts of fluid intake, heat exhaustion can occur in wildland firefighters and that other modalities besides hydration should be instituted to attenuate heat injuries on the line.

Chapter Three: Methodology

Participants and Setting

Participants in this research study will be 20 recreationally active males from the Missoula, MT area, be between the age of 18 and 40 years, and have a VO_2 max $\geq$ 45 ml/kg/min. Participants will be recruited on a volunteer basis and pass the Par-Q health/exercise questionnaire to screen for known risk factors of coronary heart disease. Additionally, an informed consent form approved by the Institutional Review Board of the University of Montana in Missoula, MT will be signed by the participant agreeing to partake in the research study. Data collection will occur in the Montana Center for Work Physiology and Exercise Metabolism's lab at the University of Montana in Missoula, MT.

Experimental Design

Preliminary Testing

PAR-Q

Preliminary testing will include a pre-screening assessment, which involves a health/exercise questionnaire (PAR-Q). Prior to any testing the participants will complete a physical activity readiness questionnaire (PAR-Q) to screen for known risk factors of coronary heart disease.

Hydrodensitometry:

Body composition will be assessed using hydrodensitometry using estimated residual volume. Participants will arrive at the lab fasted for $\geq$ 3 hours prior to body composition assessment. Body weight will be recorded on a dry weight scale (Befour Inc., Cedarburg, WI) and height will be measured. Body composition will be determined using an underwater weighing tank with digitalized and calibrated weight scales (Exertech, Dresbach, MN). Participants will be submerged underwater on the scale to determine underwater weight. Underwater weighing will continue until consistent measurements, within 100 grams, are obtained. Underwater weight will be used to calculate body density to further calculate percent body fat using estimated residual volume and the Siri equation (49).

Maximal Aerobic Capacity (VO2max)

Participants will arrive at the lab fasted for ≥ 3 hours prior to VO_2 max testing. VO_2 max testing will be performed on a treadmill ergometer (Fullvision, Inc., Newton, KS). Following a 5-minute warm-up the Bruce Protocol will be performed. This test will begin at the first stage: 1.7 mph and a 10% grade for 3 minutes. Upon completion of the first stage, the speed and intensity will continue to a consecutive increased workload. After the first stage the workload will be raised to 2.5 mph and 12% grade, 3.4 mph and 14% grade, 4.2 mph and 16% grade, and 5 mph and 18% grade, respectively (56). In order to measure VO_2 max, the participants' expired gas will be collected and analyzed every 15 seconds by a metabolic cart (Parvomedics, Inc., Sandy, UT). VO_2 max will be considered to be met when one of following criteria are met: 1) there is a plateau in VO_2 despite an increased workload; 2) Respiratory Exchange Ratio (RER) is greater than 1.10; 3) a heart rate within 10 beats of the participants' predicted maximal heart rate is reached; and 4) volitional fatigue occurs in combination of a RPE > 17.

Experimental Trials

Exercise Protocol

Participants will visit the lab for three exercise trials separated by a one week apart and they walk for 90 minutes at about 43.3°C and 40% humidity in a heat chamber (Tescor, Warminster, PA). The same treadmill ergometers (Fullvision Inc., Newton, Kansas) will be used as in the VO_2 max testing and the participants will walk at about 50% of their VO_2 max as calculated by the ACSM equation and their VO_2 max from preliminary testing. Participants will walk at this same intensity for all three trials. Exercise trials will be the same in all three trials; however, the type of drink administered will vary per trial.

Drink Administration

During the 90-minute exercise trial participants will drink between 1.5 and 3.0 L of a 6% carbohydrate beverage, which will be determined by body weight, and will be dispensed every 10 minutes. Type of beverage will vary per trial and also be randomized: room temperature beverage (about 22°C / 72°F), chilled water (about -1°C / 30°F) or frozen ice slurry (about -1°C / 30 F).

Heart Rate, Core Temperature, and Skin Temperature

Heart rate (HR), core temperature (T_c) and skin temperature (T_s) will be continuously monitored and recorded throughout the entire exercise trial. Heart rate data will be monitored by a chest-strap and receiver watch (Polar Electro, Kempele, FL). T_c will be measured with a rectal thermometer (Mallinckrodt Medical, St. Louis, MO) and T_s will be collected with a wired skin temperature sensor (Mallinckrodt Medical, St. Louis, MO) placed on the skin over the pectoralis major at about 1 to 2 inches away from the sternum. T_s and T_c data will be monitored and collected by DASYLab Software (Measurement Computing Co., Norton, MA).

Physiological Strain Index

PSI will be determined by the equation developed by Buller et al. (8) using T_c and HR data Where $T_{core(0)}$ and HR_0 were the initial core temperature and heart rate as measured at the commencement of exercise:

$$PSI = 5\,(T_{core(t)} - T_{core(0)}) * (39.5 - T_{core(0)})^{-1} + 5\,(HR_t - HR_0) * (180 - HR_0)^{-1}$$

Body Mass and Sweat Loss

Nude body mass will be measured before and after the exercise trial on a scale (Ohaus, Pine Brook, NJ located in a private room behind a closed door. Urine will be collected at the end of the trial before nude body mass is collected in order to accurately calculate sweat rate. Sweat rate will determined by changes in pre and post-exercise trial nude body mass, fluid intake, urine output, respiratory water loss, and body surface area with the following equation:

$$\text{Sweat Loss (L)} = (BW_{pre}\,\text{(kg)} + \text{Liquid Ingested (kg)}) - (BW_{post}\,\text{(kg)} + \text{Urine Weight (kg)} + \text{Respiratory Water Loss (kg)})$$

Respiratory water loss will be determined by the following equation developed by Mitchell et al. (31):

$$M_e = 0.019 \cdot VO_2\,\text{(L/min)} \cdot (44 - P_a)$$

M_e = rate of evaporative water loss (g/min)

P_a = water vapor pressure (mmHg)

Water vapor pressure will be determined by the following equation developed by Fox et al. (16):

$$P_a = 13.955 - .6584T + 0.0419T^2$$

T = temperature (°C)

Sweat loss (g) was converted to a sweat rate ($g \bullet m^{-2} \bullet min^{-1}$) utilizing the body surface area (BSA) equation (34):

$$BSA = kg^{0.5} \bullet cm^{0.5} \bullet 60^{-1}$$

BSA = body surface area (m^2)

kg = body mass in kg

cm = height in cm

Statistical Analysis

Sweat rate will be expressed relative to BSA as "$g \bullet m^{-2} \bullet min^{-1}$" and be analyzed with a one-way repeated measures ANOVA.

Core temperature will be expressed as "°C" and be analyzed with a 3 x 4 repeated measures ANOVA (trial x time).

Skin temperature will be expressed as "°C" and be analyzed with a 3 x 4 repeated measures ANOVA (trial x time).

RPE will be expressed on the scale 6-20 developed by Borg (6) and be analyzed with a 3 x 4 repeated measures ANOVA (trial x time).

PSI will be expressed on the 0 – 10 scale developed by Moran et al. (33) and be analyzed with a 3 x 4 repeated measures ANOVA (trial x time).

VO_2 max will be expressed in "ml/kg/min" and analyzed as a descriptive.

Body mass will be expressed in "kg" and analyzed as a descriptive.

Body fat will be expressed as a percentage and analyzed as a descriptive.

The level of statistical significance will be achieved at $p<0.05$ and all descriptives will be reported as mean ± SD and all physiological graphed data will be reported as mean ± SEM.

Ice Slurry and Cold Drink Reduces Exercise Induced Physiological Strain in the Heat

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Running Title: Ice Slurry and Cold Drink Reduce Heat Stress

ABSTRACT

Purpose: To determine the effects of an ice slurry beverage on heat strain and thermoregulatory responses during prolonged exercise in the heat. **Methods:** Twenty males consumed slurry (ICE, -1.4 ± 0.2 °C), cold drink (COLD, -0.7 ± 0.2 °C), or room temperature drink (RT, 21.5 ± 1.0 °C), while walking at 50% of VO_{2max} for 90 minutes in the heat (43.3 °C and 40% humidity). Heart rate (HR), core temperature (T_c), skin temperature (T_s), physiological strain index (PSI), sweat rate, and ratings of perceived exertion (RPE) were recorded. **Results:** T_c was lower at minutes 30, 60, and 90 during ICE (37.8 ± 0.1 °C, 38.3 ± 0.1 °C, 38.5 ± 0.1 °C) and COLD (37.8 ± 0.1 °C, 38.3 ± 0.1 °C, 38.7 ± 0.1 °C) vs. RT (37.9 ± 0.1 °C, 38.6 ± 0.1 °C, 39.2 ± 0.1 °C). HR was lower during ICE (138 ± 3) vs. RT (145 ± 3). PSI was lower in ICE at minutes 30, 60, and 90 (8.0 ± 0.3, 9.2 ± 0.4, 10.0 ± 0.4) and minutes 60 and 90 (9.2 ± 0.5, 10.0 ± 0.7) for the COLD compared to RT (8.4 ± 0.3, 10.3 ± 0.4, 11.5 ± 0.5). T_s and RPE were lower in the COLD vs. RT during the latter portion of the exercise. Sweat rate was lower during the ICE (11.81 ± 0.48 $g \cdot m^{-2} \cdot min^{-1}$) compared to the COLD (12.16 ± 0.51 $g \cdot m^{-2} \cdot min^{-1}$) and RT (12.95 ± 0.56 $g \cdot m^{-2} \cdot min^{-1}$). **Conclusion:** Ice slurry or a cold drink, reduces physiological strain during exercise in the heat and may act to decrease the acute risk for heat related injury.

Key Words: THERMOREGULATION, CORE TEMPERATURE, HEAT RELATED INJURY, ACCLIMATION, INTERNAL COOLING

INTRODUCTION

Paragraph 1 Athletes, military combatants, and occupational workers who regularly perform in hot environments, experience high core temperatures and physiological strain during work, competitions, and practices (2-4, 10, 11, 14, 18, 21, 32, 33, 36). Heat stress is manifested when the body is exposed to hot and humid environments causing perceived discomfort (6), which can lead to heat strain and any of the following: cardiovascular strain, central nervous system dysfunction, volitional fatigue, hyperthermia, heat exhaustion, heat stroke, or possibly death (6, 9, 10, 12). In addition to environmental conditions, the type of clothing worn and physical activity can influence the amount of heat stress induced, affecting core temperature, overall physiological strain, and increasing the risk for heat related injury (HRI) (9, 30, 38).

Paragraph 2 Previous research has demonstrated that core temperature increases more rapidly and is associated with volitional fatigue during exercise in the heat (8, 12, 15, 26, 29). Additionally, when core temperature exceeds 39°C, impairments in performance are typically observed (8, 15, 17, 23, 26, 27, 31). However, if the rise in core temperature or heart rate is mitigated, then heat strain will be reduced, thereby attenuating the overall physiological strain and subsequent HRI risk (7, 24).

Paragraph 3 To reduce heat strain during exertion in hot environments, pre-cooling techniques such as ingestion of cold water, wearing ice vests, and submersion in cold water have been utilized to lower pre-exercise core temperature. Such methods result in improved performance and extended exercise tolerance (1, 5, 16, 19, 28, 29, 34). In addition, ingestion of an ice slurry beverage at regular intervals has been demonstrated as a viable pre-cooling technique to reduce pre-exercise core temperature (34). It has been established that more energy is required to bring a volume of saline ice slurry from 0 °C to 34 °C than to bring the same volume of liquid saline from 0 °C to 34 °C (39). This finding can be attributed to the theory of enthalpy of fusion, which demonstrates that it takes 344 $kJ \cdot kg^{-1}$ of energy to melt ice to liquid at 0 °C (40). The additional heat needed to melt ice to water could create a "heat sink" if ingested in a physiological system. During exercise this might allow metabolic heat to be transferred in the phase change of ice to water, possibly reducing core temperature beyond the capabilities of cold water at the same temperature (34).

Paragraph 4 Although ice slurry has been used as a means of pre-cooling (34), its use during prolonged exercise in the heat as an attempt to modify overall physiological strain and thermoregulation has not been addressed. Thus, it is unknown if the ingestion of ice slurry during prolonged exercise would provide a better cooling effect compared to cold fluids of the same temperature.

Paragraph 5 The purpose of this study was to determine the effects of an ice slurry beverage on heat strain and thermoregulatory response during prolonged exercise in the heat. We hypothesized that ice slurry (ICE) ingestion would best mitigate the rise in core temperature, consequently reducing heat and physiological strain compared to a room temperature (RT) or a cold (COLD) beverage.

Methodology

Paragraph 6 **Participants** Twenty healthy recreationally active healthy males (age = 25.4 ± 4.9 yr, height = 177.8 ± 8.4 cm, body mass = 75.8 ± 8.8 kg, % body fat =14.5 ± 4.7 %, body surface area (BSA) = 1.93 ± 0.4 m^2, VO_{2max} = 52.1 ± 7.3 $ml \cdot kg^{-1} \cdot min^{-1}$) served as study participants. Prior to data collection participants completed the Physical Activity Readiness Questionnaire (PAR-Q) and an informed consent form approved by the University Institutional Review Board.

Paragraph 7 **Preliminary Testing** Participants arrived at the lab fasted for ≥ 3 hours prior to body composition and VO_{2max} testing. Body density was assessed using hydrodensitometry with a digital calibrated scale (Exertech, Dresbach, MN). Body mass was recorded on a dry mass scale (Befour Inc., Cedarburg, WI) and height was measured. Body composition was calculated from body density using estimated residual volume using the Siri equation. Participants performed VO_{2max} testing on a treadmill ergometer (Fullvision, Inc., Newton, KS) utilizing the standard Bruce protocol. At the end of each three-minute stage, rating of perceived exertion (RPE) was measured using the Borg Scale. Expired gas was collected and analyzed every 15 seconds from a metabolic cart (Parvomedics, Inc., Sandy, UT) to determine VO_{2max}.

Paragraph 8 **Experimental Procedures** Participants completed three experimental exercise trials separated by one week in a randomized crossover design. In each 24-hour period prior to each exercise trial, participants refrained from physical exercise, replicated their diet, and abstained from caffeine and alcohol. Participants arrived to the laboratory following a 12-hour fast and ingested 500 mL of water prior to arrival.

Paragraph 9 During each trial participants walked shirtless for 90 minutes in a 43.3 °C and 40% humidity environmental chamber (Tescor Inc., Warminster, PA). Participants completed each 90-minute heat trial at 50% of VO_{2max} using the same treadmill (Fullvision Inc., Newton, Kansas) as the preliminary testing. During the 90-minute exercise trial participants drank a total of 22.5 $g \cdot kg^{-1}$ of a 6% carbohydrate sports drink (Powerade, The Coca-Cola Co., USA) at a rate of 2.5 $g \cdot kg^{-1}$ every 10 minutes. Drinks were served at either room temperature (21.5 ± 1.0 °C), cold (-0.7 ± 0.2 °C), or in an ice slurry (-1.4 ± 0.2 °C), which was made with an ice slushy machine (Huangshi Dongbei Refrigeration Co., Huangshi, Hubei, China). The above listed means and standard deviations are based on all 180 drinks provided during each of the 3 trials.

Paragraph 10 **Measurements** Heart rate (HR), core temperature (T_c) and skin temperature (T_s) were continuously monitored and recorded throughout the entire exercise trial. Heart rate was monitored by a chest-strap and receiver watch (Polar Electro Co., Kempele, FL). Core temperature was monitored with a rectal thermometer (Mallinckrodt Medical, St. Louis, MO) that was self inserted 12 cm past the anal sphincter. To measure skin temperature (T_s), a wired skin temperature sensor (Mallinckrodt Medical Inc., St. Louis, MO) was placed on the skin over the pectoralis major 5 cm away from the sternum. Temperature data was collected by DASYLab Software (Measurement Computing Co., Norton, MA). Rating of perceived exertion was collected every ten minutes during the exercise trial.

Paragraph 11 In order to quantify heat strain induced on the subject during the exercise trial, physiological strain index (PSI) was be determined by the equation developed by Moran et al. (24) using T_c and HR data. Where $T_{c(0)}$ and HR_0 were the initial core temperature and heart rate as measured at the commencement of exercise.

$$PSI = 5\,(T_{c(t)} - T_{c(0)}) * (39.5 - T_{c(0)})^{-1} + 5\,(HR_t - HR_0) * (180 - HR_0)^{-1}$$

Paragraph 12 Nude body mass was measured before and after the exercise trial on a digital scale (Ohaus Corp., Pine Brook, NJ). Sweat loss was determined by changes in pre and post-exercise trial nude body mass, fluid intake, urine output, and respiratory water loss (22). Sweat loss (g) was converted to a sweat rate ($g \cdot m^{-2} \cdot min^{-1}$) relative to body surface area (BSA) (25).

Paragraph 13 **Statistical Analysis** Mean differences in T_c, HR, PSI, T_s, RPE, and sweat rate were analyzed at 0, 30, 60, and 90 min using a 3 x 4 repeated measure ANOVA (trial x time). Mean differences in sweat rate were analyzed by trial through a one-way repeated measure ANOVA. In the event of a significant F-ratio the LSD procedure was used to detect where differences occurred. Subject descriptive data were analyzed and reported as means ± SD.

Graphed physiological data, RPE, and sweat rate are expressed as means ± SEM. A probability of type I error less than 5% was considered significant ($p<0.05$) and all analyses were performed with SPSS Version 13 (Chicago, IL).

RESULTS

Paragraph 14 **Body Mass**. Body mass lost was significantly lower after the ICE (-0.28 ± 0.08 kg) trial compared to the COLD (-0.35 ± 0.09 kg) and RT (-0.48 ± 0.10 kg) trials. The COLD trial was also significantly lower than the RT trial.

Paragraph 15 **Core Temperature (T_c).** Core temperature demonstrated a significant trial by time interaction (Figure 1). At minutes 30, 60, and 90, T_c was significantly lower for the ICE and COLD trials compared to the RT trial. However, there was no difference between ICE and COLD trials.

Paragraph 16 **Heart Rate (HR).** Heart rate displayed a significant main effect for trial (Figure 2). HR was significantly lower during the ICE compared to the RT trials. On the contrary, there were no differences between the other trials.

Paragraph 17 **Physiological Strain Index (PSI).** Physiological Strain Index demonstrated a significant trial by time interaction (Figure 3). At minutes 30, 60, and 90, during the ICE trial, PSI was significantly lower compared to RT trials. The COLD trial also showed lower PSI at minutes 60 and 90 compared to RT trials. However, there was no difference between ICE and COLD trials.

Paragraph 18 **Skin Temperature (T_s).** Skin temperature demonstrated a significant trial by time interaction (Figure 4). At minutes 30, 60, and 90, T_s was significantly colder during the COLD compared to RT trials. However, there were no differences between the COLD and ICE trials or between the ICE and RT trials.

Paragraph 19 **Rating of Perceived Exertion (RPE).** RPE demonstrated a significant trial by time interaction (Figure 5). At minutes 60 and 90, RPE was significantly lower during the COLD compared to RT trials. However there was no other difference between trials.

Paragraph 20 **Sweat Rate.** Sweat rate was significantly lower during the ICE trial (11.81 ± 0.48 $g \cdot m^{-2} \cdot min^{-1}$) compared to the COLD ($12.16 \pm 0.51$ $g \cdot m^{-2} \cdot min^{-1}$) and RT ($12.95 \pm 0.56$ $g \cdot m^{-2} \cdot min^{-1}$) trials. The COLD trial was also significantly lower than the RT trial.

DISCUSSION

Paragraph 21 The primary purpose of the present study was to determine the effects of an ice slurry beverage on heat strain and thermoregulatory function during prolonged exercise in the heat. Our main findings indicate that, compared to a room temperature beverage, frequent ingestion of an ice slurry or a cold beverage attenuated the physiological strain induced during exercise in the heat. Second, the primary rationale for the reduction in PSI is attributed to the mitigation of T_c during the ICE and COLD trials compared to the RT trial. Additionally, ICE resulted in a significant blunting of overall sweat rate when compared to the RT and COLD trials. These findings are the first to demonstrate that the ingestion of ice slurry during exercise in the heat will impact thermoregulatory function by reducing heat and overall physiological strain. Moreover, these results suggest that both ice slurry or cold drink ingestion act similarly to reduce physiological strain, and may therefore attenuate the risk the acute HRI at the same absolute work rate in the heat compared to room temperature beverages. More importantly our data shows that the frequent provision of ice slurry or cold beverages can act to reduce physiological strain during heat stress similar to previously documented adaptations associated with short-term heat acclimation (8, 26, 27).

Paragraph 22 The achievement of a high T_c ($\geq$ 39 °C) during exercise in the heat is typically associated with a decrement in performance and a higher risk for a HRI (7, 15, 24). As seen from the findings in this present study, T_c was mitigated throughout the exercise protocol starting at 30 minutes in both COLD and ICE trial compared to the RT trial. However, there was no significant difference in T_c between the COLD and ICE trial at any time points. Previously, Lee et al. (20) showed a reduction in T_c during a cycling performance protocol at 66% $VO_{2\ peak}$ when participants precooled by drinking cool water (4 °C) 30 minutes before (300 mL every 10 minutes) and during the performance trial (100 mL every 10 minutes). However, it was not possible to discern if the observed reduction in T_c during the exercise trial was attributed to precooling and a lower initial T_c or from the continued ingestion of cold drinks throughout the exercise trial. However, the findings of the present study confirm that the frequent ingestion of cold drinks during exercise in the heat can mitigate the rise in core temperature without the need for an extended precooling modality.

Paragraph 23 At the termination of the exercise protocol, there was no difference in T_c between the ICE and COLD trials (38.5 ± 0.1 °C vs. 38.7 ± 0.1 °C, $p = 0.14$). However, if the exercise protocol were extended beyond 90 minutes, it is feasible that ingestion of an ice slurry may better mitigate the rise in T_c compared to ingestion of a COLD liquid. Since volitional fatigue has been reported to occur around 40.0 °C (27), fitting the data utilizing a linear line of best fit (coefficient of determination (R^2) value of 1.00) based on minutes 30 through 90 suggests that 40.0 °C would occur at 127, 173, and 205 minutes for RT, COLD, and ICE trials, respectively. Thus, ice slurry ingestion may be more beneficial than a cold drink during longer work bouts in the heat or in uncompensable environments where evaporative cooling is inhibited. Therefore, future work should consider a longer exercise protocol to elucidate the possibilities for differences in T_c between the COLD and ICE trials.

Paragraph 24 It should be mentioned that despite the inclusion of a 1-week washout period between trials, a significant trial order effect was noted between trial 3 compared to both trials 1 and 2. This effect may have clouded potential differences between the COLD and ICE trials. A washout period longer than 1-week should be implemented in future heat studies that evaluate acute interventions. This order effect suggests that subtle heat acclimation may be obtained with only two bouts of exercise (90 minutes at 50% VO_{2max}) in the heat (43.3 °C and 40% humidity) separated by 1-week. Remarkably, these data suggest that heat acclimation may be attained without 8-14 days of consecutive exercise in the heat as previously shown in the literature (8, 26, 27). Despite the order effect, meaningful differences between the trials were still apparent, demonstrating the physiological impact of the different treatment modalities.

Paragraph 25 Ice slurry ingestion mitigates heat strain sooner in a bout of exercise in the heat compared to COLD ingestion at an intensity of 50% VO_{2max}. Physiological strain index was first attenuated within 30 minutes for the ICE trial, whereas, the COLD trial did not mitigate PSI until 60 minutes. Buller et al. (7) suggested that a PSI $\geq$ 7.5 is associated with an increased risk for thermal injury. In the present study, after only 30 minutes of exercise in the heat, participants attained a PSI $\geq$7.5, which classified the participants at a higher risk for HRI during the final 60 minutes of the exercise in all three trials. However, it is interesting to note that the final PSI in COLD and ICE trials at 90 minutes (10.3 ± 0.6 and 9.9 ± 0.5, respectively) was less than or equal to the PSI experienced at 60 minutes in the RT trial (10.3 ± 0.4). This demonstrates that the level of heat strain induced during the final 30 minutes of the RT trial was not attained during the entire ICE and COLD trials. Furthermore, decreased T_c and PSI from ice slurry and cold drink ingestion are responses that are congruent to the physiological responses attributed to short-term heat acclimation (8, 26, 27). These findings suggest that ice slurry and cold drink may provide a temporary substitute to reduce acute heat strain when adequate heat acclimation is not possible.

Paragraph 26 Skin temperature was lower in the COLD trial relative to both the ICE and RT trials starting at 30 minutes and throughout the remainder of the exercise trial. This demonstrates the maintenance of a greater thermal gradient to better dissipate heat to the environment. Thus it would be expected that T_c would also be lower than the ICE and RT trials; however, this was not the case because T_c was similar between ICE and COLD trials. Therefore, if ice slurry served as a greater heat sink, then less metabolic heat would need to be dissipated through the skin. On the contrary, T_s is most likely lower in the COLD trial because sweat rate was higher in the COLD versus the ICE trial, allowing evaporative cooling to lower T_s. This in part could explain why skin temperature was higher in the ICE compared to COLD trial.

Paragraph 27 Sweat rate responses were different among all trials with the highest and lowest rates associated with RT and ICE, respectively. Participants noted that during the ICE trial, the ice slurry induced periodic sphenopalatine ganglioneuralgia (brain freeze). This may in part explain why sweat rate was attenuated during the ICE compared to the COLD trial since this sensation may affect the hypothalamus, which regulates sweating (13). This effect may have raised the sweat threshold, thus reducing sweat rate in the ICE trial. It is unclear whether this suggests that ice slurry may decrease the cooling capacity through the mitigation of sweat rate. However, this is not likely since the decrease in sweat rate had no effect on the rise in T_c between ICE and COLD trials. It could be argued that the reduction in T_c for the ICE and COLD trials did not require the same degree of sweating to combat the observed heat strain as compared to RT. This reduction in sweat rate would then demonstrate that the ice slurry served as a greater "heat sink" compared to the cold drink. Moreover, changes in sweat rate are congruent to the findings in body mass loss throughout the exercise trials. These findings showed that body mass loss was significantly the lowest in the ICE (-0.28 ± 0.08 kg) compared to the COLD (-0.35 ± 0.09 kg) and RT (-0.48 ± 0.10 kg) trials. Coupled with the other findings, these data suggest that ice slurry ingestion best combats dehydration compared to other drink modalities by better balancing the fluid requirements associated with thermoregulation in the heat. Since heat stress in the human leads to increased sweating (to best counter the rise in core temperature), ice slurry acts as a surrogate approach to mitigate the rise in core temp, thus reducing the requirements of other physiological mechanisms (i.e. sweating).

Paragraph 28 Perceived exertion was similar between trials from the commencement of exercise until 60 minutes. Cold drink ingestion decreased RPE at both 60 and 90 minutes of exercise while ice slurry ingestion had no effect on RPE. This is interesting because increases in RPE typically follow a rise in T_c (35). Therefore, it would be expected that RPE should also be lower during ICE relative to RT since T_c was lower. Although T_c was mitigated with ice slurry ingestion, the ICE trial may have been perceived more difficult because of anecdotal evidence of sphenopalatine ganglioneuralgia (brain freeze) and periodic gastric discomfort. This may be due to the ice slurry hindering gastric emptying on account of the time required for the slurry to melt into a liquid and rise to core body temperature, which would be supported by the work of Sun et al. (37). Their work showed that an ingested fluid temperature higher or lower than the normal T_c (37 °C) prolongs gastric emptying. Thus, because of the gastric discomfort, ice slurry may not be the best solution to mitigate heat strain during work, since cold drink has the same effect without the discomfort. Furthermore, the administration of ice slurry in the field in a hot-humid environment may be impractical because of the challenges associated with the use of a portable electronic machine in remote areas. A working crew may find it more practical to utilize a cooler with ice, water, and a small amount of rock salt to reduce the temperature of beverage bottles equivalent to that of ice slurry.

CONCLUSION

Paragraph 29 These findings are the first to suggest the ingestion of ice slurry or same temperature cold fluids during exercise in the heat will impact thermoregulatory function by reducing T_c physiological strain, thereby attenuating the overall physiological risk of a HRI. Ice slurry and cold drink may provide temporary refuge from the heat when the adequate time for heat acclimation is not possible. However, the practical implications for providing ice slurry should be considered during certain events, possibly making colder beverages a more realistic choice when combating acute heat strain.

FIGURES

Figure 1.

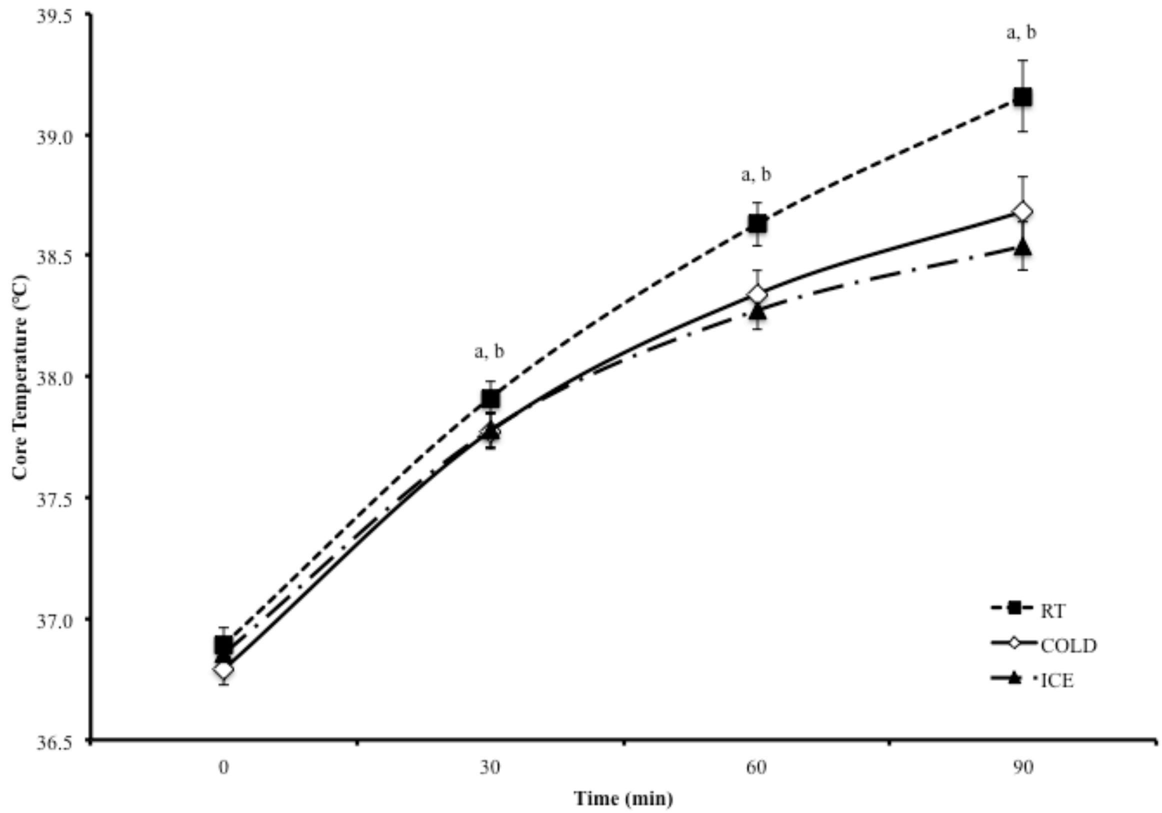


Figure 2.

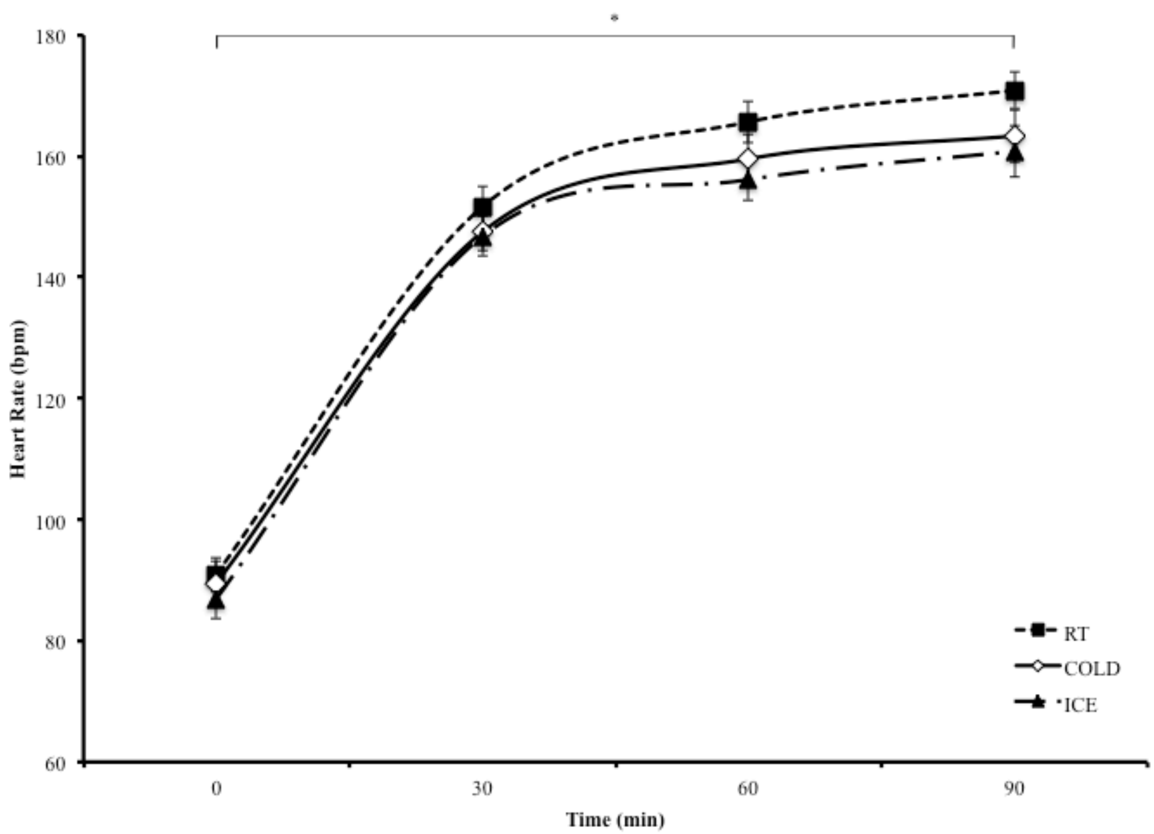

*
180
160
140
120
100
80
60
Heart Rate (bpm)
0
30
60
90
Time (min)
RT
COLD
ICE

Figure 3.

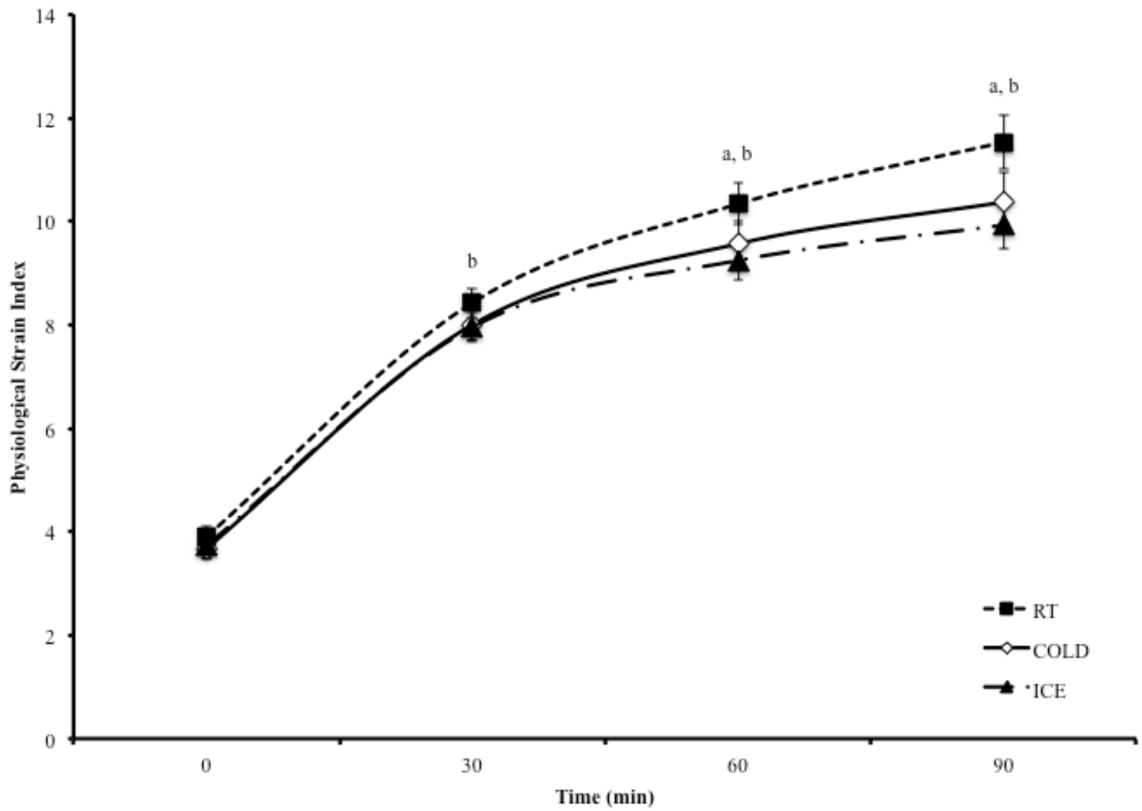

14
12
10
8
6
4
2
0
Physiological Strain Index
b
a, b
a, b
RT
COLD
ICE
0
30
60
90
Time (min)

Figure 4.

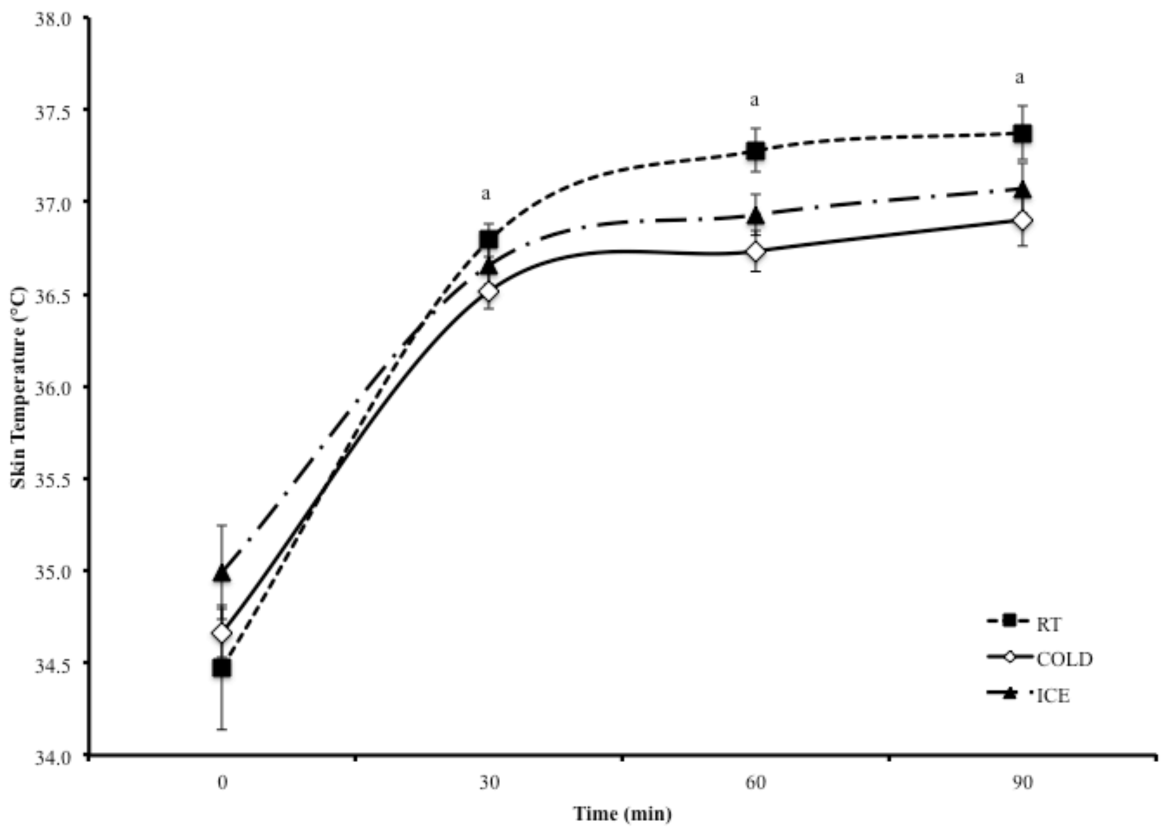
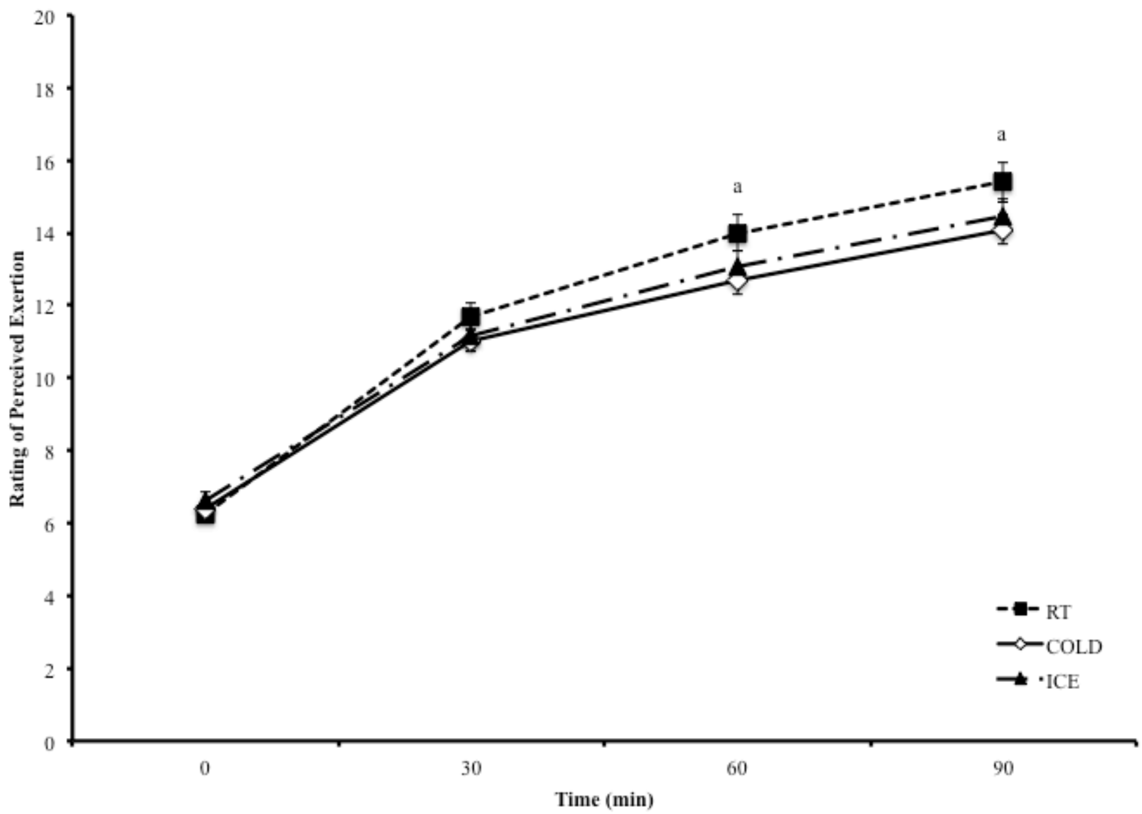


Figure 5.


20
18
16
14
12
10
8
6
4
2
0
Rating of Perceived Exertion
a
a
RT
COLD
ICE
0
30
60
90
Time (min)

LEGENDS FOR FIGURES

Figure 1. Core temperature during 90 minutes of walking in the heat for ICE, COLD, and RT trials. Trial interaction at minutes 30, 60, and 90: a) $p < 0.05$ between COLD and RT; b) $p < 0.05$ between ICE and RT trials.

Figure 2. Heart rate during 90 minutes of walking in the heat for ICE, COLD, and RT trials. Main effect for trial: * $p < 0.05$ between ICE and RT trials.

Figure 3. Physiological strain during 90 minutes of walking in the heat for ICE, COLD, and RT trials. Trial interaction at minutes 30, 60, and 90: a) $p < 0.05$ between COLD and RT trials; b) $p < 0.05$ between ICE and RT trials.

Figure 4. Skin temperature during 90 minutes of walking in the heat for ICE, COLD, and RT trials. Trial interaction at minutes 30, 60, and 90: a) $p < 0.05$ between COLD and RT trials.

Figure 5. Rating of perceived exertion during 90 minutes of walking for ICE, COLD, and RT trials. Trial interaction at minutes 60 and 90: a) $p < 0.05$ between COLD and RT trials.

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