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Cooling Effectiveness of Modified Cold-Water Immersion Method Following Exercise-Induced Hyperthermia

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Cooling Effectiveness of Modified Cold-Water Immersion Method
Following Exercise-Induced Hyperthermia

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by

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Abstract

Context: Recommended treatment of exertional heat stroke (EHS) includes whole body cold-water immersion (CWI); however, remote locations, spatial or monetary restrictions challenge CWI feasibility. Thus, the development of a modified, portable CWI method would allow for optimal treatment of EHS when restrictions apply. ***Objective:*** Determine cooling efficacy of modified CWI (tarp assisted cooling with oscillation; TACO) following exertional hyperthermia. ***Design:*** Randomized, crossover controlled trial. ***Setting:*** Environmental chamber (33.4 ± 0.8°C, 55.7 ± 1.9% relative humidity). ***Patients or Other Participants:*** Sixteen (9 males, 7 females) volunteers (26 ± 4.7y, 1.76 ± 0.09m, 72.5 ± 9.0kg, 20.7 ± 7.1%body fat) with no history of compromised thermoregulation participated. ***Interventions:*** Participants completed volitional exercise (cycling or treadmill) until a rectal temperature (T_{re}) ≥39.0°C. Following exercise, participants transitioned to a semi-recumbent position on a tarp until T_{re} reached 38.1°C or until 15 minutes elapsed during both control (no immersion; CON) and TACO (immersion in 151L of 2.1 ± 0.8°C water). ***Main Outcome Measures:*** T_{re}, heart rate (HR), and blood pressure (reported as mean arterial pressure, MAP), were assessed pre- and post-cooling. Statistical analyses included repeated measures ANOVA with appropriate post-hoc t-tests and Bonferroni correction. ***Results:*** T_{re} prior to cooling was not different between conditions (CON: 39.27 ± 0.26°C, CWI: 39.30 ± 0.39°C; P=0.62; ES=-0.09) whilst post-cooling T_{re} was decreased in TACO (38.10 ± 0.16°C) compared to CON (38.74 ± 0.38°C, $t_{15}=-8.84$; P<0.001; ES=2.27). Cooling rate was significantly faster during TACO (0.14 ± 0.06°C/min) compared to CON (0.04 ± 0.02°C/min, P<0.001; ES=2.21). Decreases in heart rate did not differ between TACO and CON ($t_{15}=-1.81$; P=0.09; ES=0.45). MAP was significantly greater post-cooling in TACO (84.2 ± 6.6mmHg) compared with CON (67.0 ± 9.0mmHg, P<0.001; ES=2.25). ***Conclusions:*** TACO provided significantly faster cooling than CON. When monetary or spatial restrictions are present, TACO represents an effective alternative to traditional CWI in emergency treatment of exertional hyperthermia.

Acknowledgments

I'd like to thank my committee for their support throughout this entire process, as well as my classmates and the members of the Human Performance Lab who helped make TACO possible.

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List of Published Papers

Chapter IV. Luhring KE, Butts CL, Smith CR et al. (2016) *Cooling Effectiveness of Modified Cold-Water Immersion Method Following Exercise-Induced Hyperthermia*. Manuscript submitted for publication.

I. Introduction

Brief Background

Exertional heat stroke (EHS) is one of the most common causes of sudden death among active populations such as athletes or military personnel. This is especially true during the summer months when ambient temperatures and/or humidity are increased. Once a patient is diagnosed with EHS, it is important to cool their core body temperature to below 38.9° C as quickly as possible to limit the chance of morbidity and mortality. The National Athletic Trainers' Association position statement on preventing sudden death in sport states that "cold water immersion is the most effective cooling modality for patients with EHS."[1] The recommended method for cold water immersion (CWI) is circulated ice water immersion up to the neck or clavicles in large plastic or metal tubs. However, for some clinicians, the purchase or transport and set up of these tubs is difficult due to monetary or spatial restrictions (trail races, small high schools, etc.).

The tarp assisted cooling (TACO) method was conceived as a portable and inexpensive alternative to CWI tubs. This method uses a basic plastic tarp as the container for ice water. The patient is placed on the tarp and then the sides are elevated to create a make-shift tub to contain ice water. TACO is known to have been used in the military and during the 2012 Boston Marathon to effectively treat EHS victims. Despite successful anecdotal reports, there have been no studies investigating the effectiveness of TACO for reducing hyperthermia, and therefore no guidelines for its use in the field have been established.

Purpose of the Study

The purpose of this study is to validate the efficacy of using TACO in the field to reduce hyperthermia. We will have participants exercise to induce increased core temperatures as measured via rectal thermometry and then perform a randomized controlled trial with control and cooling conditions. We will also monitor heart rate, blood pressure and the perceptual measures of thermal sensation, perceived thirst, and muscle pain. The aim of this study is to: 1) confirm that TACO cools faster than CON and 2) establish the cooling rate that can be achieved using TACO.

Hypotheses

We hypothesize that TACO will cool subjects significantly faster than CON.

References

1. Casa DJ, DeMartini JK, Bergeron MF, et al. National athletic trainers' association position statement: Exertional heat illnesses. *J Athl Train.* 2015;50(9):986-1000.

II. Review of Literature

Exertional Heat Stroke and Whole Body Cooling

The diagnostic criteria for EHS includes a core temperature >40.5°C along with alterations in central nervous system function. This elevation in core temperature during exercise occurs because the body's thermoregulatory system is no longer capable of dissipating metabolic heat, either because the body is producing excessive amounts of heat or because there is an inhibition of effective heat loss. Individuals more susceptible to EHS tend to be less physically fit, not properly acclimatized to heat, suffering from acute illness, or in a state of hypohydration.[2,3] In order to counteract the effects of EHS, it is important to cool the body to 38.9°C within 30 minutes of onset.[4] There are 4 ways for the body to disperse heat: radiation, convection, evaporation, and conduction.

All heat transfer is dependent upon gradients between the source giving away and the source receiving heat. Heat always travels from an area of high temperature to an area of lower temperature. Radiation is heat transfer through electromagnetic energy in the infrared spectrum and does not require physical contact between objects for energy transfer. Since the human body is generally warmer than the surrounding air, the infrared waves are emitted by the body into its surroundings. Convection occurs when heat is transferred to either water or air moving over the skin. The faster that the air or water moves over the skin the more turnover of unheated substance there is next to the hot body and the greater amount of heat that can be transferred into the surrounding environment. Water is about 40 times more effective than air at transferring heat to or from the body.[5] Evaporation is the main method of heat transfer that is used by the body in high temperatures. When the body produces sweat, the heat is transferred into the water on our skin, which evaporates and removes that heat from the body. However, if humidity is high, this method becomes less effective since the air is already more saturated with gaseous water. In this case, the sweat will remain on the skin or drip off, which does not affect heat loss and merely dehydrates the body. The last method of heat loss is conduction, which occurs when a hot object is physically in contact with a cooler one allowing the heat to transfer. For the human body in an average day, this method makes up only about 1% of the total heat exchange and therefore does not noticeably contribute to cooling.[5]

Using the principles of these types of heat loss, many different strategies for cooling patients with EHS have been attempted. Emergency room methods include using intravenous (IV) fluids to both rehydrate and lower core temperature as well as more advanced technological methods. In a 1979 study examining heat casualty victims of an Australian fun run four different methods of cooling were used, including three that used administration of room temperature IV fluids.[3] The treatment applied was dependent upon the initial rectal temperature and was either ice-wet towel application, ice-wet towel application with IV fluid, cold pack application at the neck, axillae, and groin with IV fluid administration, or only IV fluids. Although there was insufficient information to calculate a cooling rate for those patients who received ice-wet towels only, the cooling rates for the three other treatments were $0.097°C \cdot min^{-1}$, $0.089°C \cdot min^{-1}$, and $0.076°C \cdot min^{-1}$ respectively. A case study by Broessner et al. discusses the use of a machine called the Cool Gard 3000 in the treatment of a hyperthermic individual.[6] By inserting a Foley bladder catheter into the left superior vena cava and maintaining the temperature of saline flowing through the bladder at 37°C they were able to achieve a maximum cooling rate of $0.6°C \cdot hour^{-1}$ ($0.01°C \cdot min^{-1}$). This is by no means rapid cooling of patients, and the practicality of easy field use for either of these methods is non-existent.

By examining the physiology of thermoregulation, many clinicians have attempted methods of cooling that focus on convection and evaporation. The argument for many of these methods is that immersing the body in cold water is detrimental to cooling due to vasoconstriction of skin blood vessels as well as causing shivering that creates a paradoxical increase in core temperature.[7,8,9,10] Other arguments against CWI is that it can be a shock to the cardiac system and is generally uncomfortable for the patient.[7,8,11] The simplest evaporation/convection method includes removing the patient from the sun and allowing a breeze to blow across them. A study where participants were moved to the shade and had a breeze provided by a fan at 1.5 mph for continuous airflow resulted in a cooling rate of 0.11±0.04°C·min^{-1}.[12] Another evaporation technique was studied at the Falmouth Road Race and involved exposing patients to ambient air while wrapped in wet towels, which resulted in a cooling rate of 0.12±0.02°C·min^{-1}.[8] An analysis done on 52 cases of EHS in the Israeli Defense Forces between 1996-2003 showed that their method of moving the victims to the shade and continually fanning and dousing them with tepid water produced a cooling rate of 0.14±0.11°C·min^{-1}.[11] The authors hail this method as a viable field cooling technique which does not require excessive amounts of equipment required by some evaporative techniques. One of those equipment intensive techniques uses a system known as the body cooling unit (BCU), which consists of a suspended net platform for the patient to lie on while 15°C water is sprayed in a fine mist above and below the body.[13] Warmed air (45-48°C) is trained on the body at 30 m·min^{-1}, which keeps the skin temperature above 30°C in order to maintain "cutaneous vasodilation and ensures a high rate of heat-loss from core to skin."[13] By analyzing this method on 18 cases of EHS, they found an average cooling rate of 0.078°C·min^{-1} with a range of 0.013 to 0.225°C·min^{-1}. Another attempt at a convenient field method involved the use of a helicopter to create a downdraft while the patient was continuously doused in 30-32°C water.[9] In the three patients studied, an average cooling rate of 0.104°C·min^{-1} was observed. Although helicopters are not normally available at athletic events, the authors of this case series point out that they are easily available in most military settings and that large fans can replace helicopters in other cases. However, for athletic events that are held in remote areas, electricity to power fans is not readily available, and the authors mention that this method is only viable in an "appropriately warm environment" since the goal is to not cause vasoconstriction of the peripheral vasculature. Since EHS does not always occur in warm environments, this method of cooling may not be effective in all field cases.

Despite the criticisms of evaporative cooling supporters, CWI has become the gold standard for treatment of EHS and is recommended by the American College of Sports Medicine, NATA and the Korey Stringer Institute.[1,14] This method is based on conduction as the means of heat loss, as well as convection if the water is circulated. It's effectiveness as a cooling modality may be due to hydrostatic pressure increasing venous return to the heart as well as the high temperature gradient between the skin and the water.[8,10,15,16] Contrary to the belief that CWI caused patients to shiver and actually increase their heat production, multiple studies have shown that the colder the water is the less likely the patient is to shiver during treatment.[8,10] Another study showed that even if subjects started to shiver, the heat produced does not reduce the cooling effectiveness of CWI.[16]

There is a debate on whether cold-water or ice-water immersion is the more effective modality. A study by Clements et al. showed no significant difference in cooling rates between cold-water (14.03 ± 0.28°C) and ice-water (5.15 ± 0.20°C) in hyperthermic runners (both 0.16±0.01°C·min^{-1}).[17] The study by Proulx et al. that tested water at 2, 8, 14, and 20°C showed significant differences in cooling rate between the coldest water temperature and all others (0.35±0.14, 0.19±0.07, 0.15±0.06, and 0.19±0.10°C·min^{-1} respectively).[10] This result was supported by Armstrong et al. who found that using ice water at a temperature between 1 and 3°C resulted in a cooling rate of 0.20±0.02°C·min^{-1}.[8] More recently, a study has been published synthesizing 18 years of finish line medical tent patient records at the Falmouth Road Race. In the 274 cases of EHS observed, CWI led to 100% survival and a 0.22±0.11°C·min^{-1} average cooling rate.[18]

Oscillation of the water is important during CWI so that cold water is constantly in contact with the skin. If a patient is allowed to remain stagnant in water, a buffer area forms over the surface of their skin that is warmer than surrounding water. This will have a detrimental effect on cooling rate because conduction of heat from the body into the water will be impaired if the water becomes a warmer temperature. By oscillating the water, the principles of convection are also applied, enhancing cooling rates. The differential movement of water over the skin provided by the oscillation also acts like a massage. Massage increases blood flow to an area, possibly by stimulating the sympathetic nervous system which results in temporary vasodilation.[19]

Cardiovascular Reaction During Cooling

During exercise, heart rate increases directly in proportion to the increase in exercise intensity. This allows for an increase in circulation of blood throughout the body and greater flow of oxygen to working muscles.[20] When immersed in cold water, the body usually reacts in a very specific way, often termed “cold shock.” There is the initial gasp brought on by the cold temperature, followed by hyperventilation, tachycardia, and hypertension.[21,22] Peripheral vasoconstriction also occurs in order to limit body heat loss to the surrounding environment.

However, it has been shown that CWI post-exercise causes greater decreases in heart rate than seen in control trials.[10,23,24] Another study on joggers showed a trend towards greater decrease in heart rate of CWI subjects, but they were not significantly different from controls.[12] Heart rate has also been looked at as an indicator of shivering during CWI. In the study by Proulx et al., subjects showed a progressive decline in heart rate during immersion so any sudden sustained increase in heart rate was noted as the onset of the shivering response.[10]

Blood pressure reacts similarly to heart rate during exercise, showing an increase in systolic blood pressure with increasing intensity. Diastolic blood pressure tends to remain the same. As mentioned earlier, immersion in cold water without exercising beforehand causes an increase in blood pressure.[21, 22] A systematic review done by Bleakley and Davison found that blood pressure normalized after 30 minutes of immersion, and that the drastic cardiovascular changes seen with CWI began adapting in most individuals after 3 min.[25]

Perceptual Alterations During Cooling

Thermal sensation in the human body is perceived by thermoreceptors, many of which can be found in the skin. Therefore, it stands to reason that even with a core temperature elevated by exercise, an individual immersed in cold water would perceive themselves as being cold. This was found in a study by DeMartini et al., which showed a significant difference in thermal sensation between subjects undergoing CWI to subjects who sat in the sun.[24]

Heat stress has been shown to increase thirst sensation compared to cooler environments.[26] However, there has been a paucity of research on post-exercise thirst sensation during cooling. The aforementioned study by DeMartini et al. found no significant differences between pre- and post-cooling thirst sensation, which suggests that cooling has no effect on the body's perception of thirst.[24]

There is abundant research on the effects of CWI on post-exercise muscle soreness for the purposes of recovery. A review by Bleakley et al. came to the conclusion that there was some evidence that delayed onset muscle soreness was decreased by CWI.[27] There has been little interest in investigating the use of CWI for the immediate relief of post exercise muscle pain.

Assumptions

Assumptions of this study include honesty on the medical history form regarding exclusion criteria, honesty on ratings for perceptual measures, and proper compliance with study protocol (i.e. matching food intake on 24-hour diet logs before trials).

Limitations

Our participants will consist of a convenience sample of regularly active males and females from the Northwest Arkansas area. Since they are volunteering for exercise, participants will likely all be of an average healthy body type and their cooling rates using this modality may not be reflective of cooling rates seen in larger individuals such as football linemen. There will be no measurement of the rate of water oscillation between participants which may lead to differences in cooling rates.

Delimitations

It is unethical to induce EHS in participants; therefore, our cooling rates may not be reflective of cooling rates that would be seen in actual patients.

References

1. Casa DJ, DeMartini JK, Bergeron MF, et al. National athletic trainers' association position statement: Exertional heat illnesses. *J Athl Train.* 2015;50(9):986-1000.

2. Epstein Y, Moran DS, Shapiro Y. Exertional heatstroke in the Israeli defense forces. *Medical Aspects of Harsh Environments*. 2001;1:281-292.

3. Richards D, Richards R, Schofield PJ, Ross V, Sutton JR. Management of heat exhaustion in Sydney's the sun city-to-surf run runners. *Med J Aust*. 1979;2(9):457-461.

4. Heled Y, Rav-Acha M, Shani Y, Epstein Y, Moran DS. The" golden hour" for heatstroke treatment. *Mil Med*. 2004;169(3):184-186.

5. Casa DJ. *Preventing sudden death in sport and physical activity.* Jones & Bartlett Publishers; 2011.

6. Broessner G, Beer R, Franz G, et al. Case report: Severe heat stroke with multiple organ dysfunction–a novel intravascular treatment approach. *Crit Care*. 2005;9(5):R498-501.

7. Barner HB, Wettach GE, Masar M, Wright DW. Field evaluation of a new simplified method for cooling of heat casualties in the desert. *Mil Med*. 1984;149(2):95-97.

8. Armstrong LE, Crago AE, Adams R, Roberts WO, Maresh CM. Whole-body cooling of hyperthermic runners: Comparison of two field therapies. *Am J Emerg Med*. 1996;14(4):355-358.

9. Poulton TJ, Walker RA. Helicopter cooling of heatstroke victims. *Aviat Space Environ Med*. 1987;58(4):358-361.

10. Proulx CI, Ducharme MB, Kenny GP. Effect of water temperature on cooling efficiency during hyperthermia in humans. *J Appl Physiol*. 2003;94(4):1317-1323. doi: 10.1152/japplphysiol.00541.2002.

11. Hadad E, Moran DS, Epstein Y. Cooling heat stroke patients by available field measures. *Intensive Care Med*. 2004;30(2):338-338.

12. Clapp AJ, Bishop PA, Muir I, Walker JL. Rapid cooling techniques in joggers experiencing heat strain. *Journal of Science and Medicine in Sport*. 2001;4(2):160-167.

13. Khogali M, Weiner J. Heat stroke: Report on 18 cases. *The Lancet*. 1980;316(8189):276-278.

14. American College of Sports Medicine, Armstrong LE, Casa DJ, et al. American college of sports medicine position stand. exertional heat illness during training and competition. *Med Sci Sports Exerc*. 2007;39(3):556-572.

15. Costrini A. Emergency treatment of exertional heatstroke and comparison of whole body cooling techniques. *Med Sci Sports Exerc*. 1990;22(1):15-18.

16. Proulx C, Ducharme M, Kenny G. Safe cooling limits from exercise-induced hyperthermia. *Eur J Appl Physiol*. 2006;96(4):434-445.

17. Clements JM, Casa DJ, Knight J, et al. Ice-water immersion and cold-water immersion provide similar cooling rates in runners with exercise-induced hyperthermia. *J Athl Train*. 2002;37(2):146-150.

18. Demartini JK, Casa DJ, Stearns R, et al. Effectiveness of cold water immersion in the treatment of exertional heat stroke at the falmouth road race. *Med Sci Sports Exerc*. 2015;47(2):240-245.

19. Starkey C. *Therapeutic modalities.* FA Davis; 2013.

20. Kenney WL, Wilmore J, Costill D. *Physiology of sport and exercise with web study guide.* Human kinetics; 1999.

21. Datta A, Tipton M. Respiratory responses to cold water immersion: Neural pathways, interactions, and clinical consequences awake and asleep. *J Appl Physiol*. 2006;100(6):2057-2064. doi: 10.1152/japplphysiol.01201.2005.

22. Srámek P, Simecková M, Janský L, Savlíková J, Vybíral S. Human physiological responses to immersion into water of different temperatures. *Eur J Appl Physiol*. 2000;81(5):436-442.

23. Halson SL, Quod MJ, Martin DT, Gardner AS, Ebert TR, Laursen PB. Physiological responses to cold water immersion following cycling in the heat. *Int J Sports Physiol Perform*. 2008;3(3):331-346.

24. DeMartini JK, Ranalli GF, Casa DJ, et al. Comparison of body cooling methods on physiological and perceptual measures of mildly hyperthermic athletes. *J Strength Cond Res*. 2011;25(8):2065-2074.

25. Bleakley CM, Davison GW. What is the biochemical and physiological rationale for using cold-water immersion in sports recovery? A systematic review. *Br J Sports Med*. 2010;44(3):179-187.

26. Greenleaf JE. *Environmental issues that influence intake of replacement beverages.* Fluid Replacement and Heat Stress. Washington, DC: National Academy Press; 1994.

27. Bleakley C, McDonough S, Gardner E, et al. Cold-water immersion (cryotherapy) for preventing and treating muscle soreness after exercise. *Sao Paulo Medical Journal*. 2012;130(5):348-348.

III. Methods

Participants

Sixteen participants were recruited from the surrounding community via word of mouth and the newswire to voluntarily participate in two exercise/treatment trials in the heat (1 control and 1 cold water immersion). Upon being recruited, participants attended a brief (~30min) session covering the informed consent form and details of the study. During this time participants also turned in a medical history form to verify that no exclusionary conditions exist. For this study exclusion criteria included:

1. Previous heat exhaustion or heat stroke within the past 3 months
2. Current illness or musculoskeletal injury
3. Hypertension where vigorous exercise is contraindicated
4. Allergy to cold.

Once medical clearance and informed consent were obtained, participants who qualified also had their body composition assessed via dual energy x-ray absorptiometry (DEXA). Participants were then scheduled for 2 separate trials at least 1 week apart to prevent heat acclimation. Participants were asked to refrain from alcohol use and exercise for 24 hours, and caffeine use for 12 hours prior to each trial. For 24 hours prior to each trial, participants recorded their food/fluid intake on a standard diet log.

Instrumentation

Participants were provided with a heart rate strap to wear for the duration of exercise and treatment (Polar, Inc., Lake Success, NY, USA). A blood pressure cuff was placed on the upper arm and three ECG electrodes were attached (right and left subclavicular fossa, and right anterior abdominal line) to allow for arterial blood pressure to be measured by auscultation of the brachial artery via electrosphygmomanometry (Tango+, SunTech, Raleigh, NC, USA). A rectal thermistor with tape marking 12 cm from the tip was provided to each participant. After receiving instructions from a researcher on proper insertion of the thermistor, participants were directed to the bathroom in the lab. Participants were then educated on perceptual measures that were repeated throughout exercise and treatment. These perceptual measures included rate of perceived exertion, perceived thirst, thermal sensation, and muscle pain.

Experimental Design

This study was a randomized, crossover controlled trial. Trials consisted of 2 distinct portions:

1. Exercise in a Hot Environment

After instrumentation was completed, participants entered an environmental chamber which was set at a temperature between 30-35°C and 40-60% relative humidity. Participants then sat on a chair for 10 minutes followed by the collection of baseline values for rectal temperature, blood pressure, heart rate, and the perceptual measures. Immediately following baseline measurements, participants had the blood pressure cuff and electrode leads removed and then moved to and began exercise on either a cycle or treadmill. During the first trial, exercise intensity was self-selected by participants and recorded by the researcher such that it was sufficient to elevate core temperature to at least 39°C. Rectal temperature and heart rate was recorded continuously via computer (LabChart7, ADInstruments, Inc., Colorado Springs, USA) at 50Hz during exercise and treatment. Perceptual measures (thermal perception, rate of perceived exertion, and thirst sensation) were taken every 10 minutes. Exercise was immediately ceased if a participant began to experience signs/symptoms of exertional heat illness or their temperature reached 41°C. During exercise, participants were encouraged to consume body temperature water ad libitum. Consumption was recorded by pre- and post- exercise bottle mass. Once participants reached a core temperature of at least 39°C, they ceased exercise and moved to the cold water immersion portion of the trial. The second trial was conducted in a manner such that core temperature was elevated to the same level by matching exercise intensity. The last five minutes of exercise were exactly matched between trials in order to avoid differential cooling as a result of metabolic heat productions at the cessation of exercise.

2. Cold Water Immersion Treatment

Treatment will be assigned in a randomized counterbalanced crossover design such that subjects performed cold water immersion during one trial and control (no immersion) during one trial. Prior to starting the treatment portion, participants were re-instrumented with the blood pressure cuff and leads to the electrodes to measure arterial blood pressure. Re-instrumentation time was held to five minutes from end of exercise to start of treatment for each participant. The protocol consisted of a standard tarp with a researcher at each corner and one on each edge. The subject laid on the tarp in a semi-recumbent position, followed by the researchers elevating their respective corners, forming a “taco” shape.

During the cold water immersion trial, 40 gallons of ice water was then poured on and around the subject using four 10 gallon water coolers, ensuring the head and upper chest of the participant is out of the water and that the water level rose to at least the level of the participant’s iliac crest. Participants remained immersed for 15 minutes or until their core temperature returned to 38.3°C (~101°F). Following immersion, participants exited the tarp, toweled dry, and returned to sitting on a chair inside the environmental chamber for at least 30 minutes (to monitor for signs of hypothermia and collect physiological and perceptual values). Participants then exited the chamber to towel completely dry and remove all instrumentation to complete the trial.

During the control trial, the subject laid on the tarp in the semi-recumbent position inside the environmental chamber for 15 minutes with no immersion. The participants then moved to the chair and sat inside the environmental chamber for at least 30 minutes at which time they also toweled completely dry and removed their instrumentation to complete the trial. For both treatments, physiological data (rectal temperature and heart rate) was monitored continuously during and following treatment. Blood pressure was taken every 2 minutes during treatment, and at 2, 5, 8, 10, 20, and 30 minutes post treatment. Perceptual measures were taken at the beginning and end of treatment, and every 10 minutes post treatment.

Data Analysis

Statistical analysis was completed using IBM SPSS Statistics v23.0 (IBM, Armonk, NY, USA). Analysis was done on data collected pre- and post-treatment for all measures using repeated measures ANOVA to assess the effects of treatment between trials. Cooling rates were analyzed using a paired t-test. An alpha of <0.05 was set a priori and any statistically significant values were run through post-hoc analysis with appropriate Bonferroni correction. Effect size (ES) was calculated using G*Power Version 3.1.9.2 (Universitat Kiel, Germany). As no differences between males and females were identified for any variable, data were combined for analyses. Results are presented as means ± standard deviations.

IV. Manuscript

Cooling Effectiveness of Modified Cold-Water Immersion Method Following Exercise-Induced Hyperthermia

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ABSTRACT

Context: Recommended treatment of exertional heat stroke (EHS) includes whole body cold-water immersion (CWI); however, remote locations, spatial or monetary restrictions challenge CWI feasibility. Thus, the development of a modified, portable CWI method would allow for optimal treatment of EHS when restrictions apply. ***Objective:*** Determine cooling efficacy of modified CWI (tarp assisted cooling with oscillation; TACO) following exertional hyperthermia. ***Design:*** Randomized, crossover controlled trial. ***Setting:*** Environmental chamber (33.4 ± 0.8°C, 55.7 ± 1.9% relative humidity). ***Patients or Other Participants:*** Sixteen (9 males, 7 females) volunteers (26 ± 4.7y, 1.76 ± 0.09m, 72.5 ± 9.0kg, 20.7 ± 7.1%body fat) with no history of compromised thermoregulation participated. ***Interventions:*** Participants completed volitional exercise (cycling or treadmill) until a rectal temperature (T_{re}) ≥39.0°C. Following exercise, participants transitioned to a semi-recumbent position on a tarp until T_{re} reached 38.1°C or until 15 minutes elapsed during both control (no immersion; CON) and TACO (immersion in 151L of 2.1 ± 0.8°C water). ***Main Outcome Measures:*** T_{re}, heart rate (HR), and blood pressure (reported as mean arterial pressure, MAP), were assessed pre- and post-cooling. Statistical analyses included repeated measures ANOVA with appropriate post-hoc t-tests and Bonferroni correction. ***Results:*** T_{re} prior to cooling was not different between conditions (CON: 39.27 ± 0.26°C, CWI: 39.30 ± 0.39°C; P=0.62; ES=-0.09) whilst post-cooling T_{re} was decreased in TACO (38.10 ± 0.16°C) compared to CON (38.74 ± 0.38°C, $t_{15}=-8.84$; P<0.001; ES=2.27). Cooling rate was significantly faster during TACO (0.14 ± 0.06°C/min) compared to CON (0.04 ± 0.02°C/min, P<0.001; ES=2.21). Decreases in heart rate did not differ between TACO and CON (t_{15}=-

1.81;P=0.09; ES=0.45). MAP was significantly greater post-cooling in TACO (84.2 ± 6.6mmHg) compared with CON (67.0 ± 9.0mmHg, *P*<0.001; ES=2.25). ***Conclusions:*** TACO provided significantly faster cooling than CON. When monetary or spatial restrictions are present, TACO represents an effective alternative to traditional CWI in emergency treatment of exertional hyperthermia.

Key Words: tarp-assisted cooling, heat strain, heat illness, exertional heat stroke

INTRODUCTION

Exertional heat stroke (EHS) is one of the most common causes of sudden death among athletes and military personnel.[1-4] Risk increases during summer months when ambient temperature and relative humidity are increased.[3] The addition of protective equipment further compromises normal thermoregulation.[5] Diagnostic criteria of EHS includes a core temperature of >40.5°C along with alterations in central nervous system function.[1,6] Once a patient is diagnosed, it is critical that their core body temperature be reduced to below 38.9°C as quickly as possible in order to prevent sequelae and limit chances of mortality.[6,7]

The National Athletic Trainers' Association recommends whole-body cold-water immersion (CWI) as the best method for treating EHS.[6] CWI is optimized (i.e., faster cooling) with colder water temperatures, particularly with continuous water circulation to prevent a barrier of warm water from forming adjacent to the patient.[6,8-11] Oscillating the water provides a massaging effect to the skin, which increases vasodilation of the peripheral vasculature.[12] Therefore, circulated cold water allows more blood to be cooled at the periphery through conduction and convection, and subsequently, transported to the core.

Cold-water immersion typically requires a large tub filled with water and ice to be on site and ready for use during activities. However, a recent study by Mazerolle et al[13] found that many athletic trainers do not implement this method due to lack of resources and the lack of time in daily workloads to maintain the tub. It is also infeasible to transport these large tubs to certain venues, such as military drills and off road races. Although some also contend that patient comfort and cardiovascular stress are compromised with CWI,[12] it consistently demonstrates successful outcomes.[6,8-12,14]

A recent review of cooling rates for a variety of modalities identified categories for cooling rates.[11] These labeled categories for cooling rates were identified based on how long it would take an EHS patient to be cooled appropriately. In order for efficient cooling to take place in less than 30 minutes, acceptable whole body cooling must be $\geq 0.078°C \cdot min^{-1}$.[11] Typical cooling rates for CWI range between 0.129[8] and $0.350°C \cdot min^{-1}$,[9] and are known to produce 100% survival when used for EHS patients.[14] In some military and athletic situations, continual rotation of ice-soaked towels or sheets have had successful outcomes as an alternative to CWI.[16] Limited evidence to date supports the use of CWI alternatives for the treatment of exercise induced hyperthermia.

The tarp assisted cooling with oscillation (TACO) method was developed to offset deterrents to CWI. This method uses a simple plastic tarp held by staff members as the container for cold water while the patient sits or lies in the middle. TACO is portable and inexpensive (<\$20), and has been successfully used in the military and during the 2012 Boston Marathon to treat EHS victims (C. Troyanos, oral communication, May 2012; M.B. Smith, oral communication, June 2011). Despite anecdotal reports of the TACO methods success, no studies have been conducted to determine its effectiveness. The purpose of this study was to test the efficacy of TACO and determine the cooling rate achievable through this method. It was hypothesized that TACO would cool participants at acceptable rates (≥0.078°C·min^{-1}) following exercise hyperthermia.

METHODS

Study Design

This study was conducted using a randomized, crossover controlled trial. The study procedures were approved by the Institutional Review Board. Trials consisted of two distinct portions; exercise and treatment. Our exercise protocol was self-paced for the first trial and matched for the second, and its purpose was to induce hyperthermia. Our treatment portion was used to compare the treatments via separate trials (one with TACO, and one CON).

Participants

Sixteen participants (9 males, 7 females; 26 ± 4.7y, 1.76 ± 0.09m, 72.5 ± 9.0kg, 20.7 ± 7.1% body fat) were recruited from the surrounding community via word of mouth and electronic media to voluntarily participate in two exercise/treatment trials in the heat (1 control; CON, and 1 TACO). Upon being recruited, participants attended a brief (~30min) session covering the informed consent form, medical history form, and details of the study. During this time, participants turned in a medical history form to verify that no exclusionary conditions existed. Exclusion criteria included previous heat exhaustion or heat stroke within 3 months, current illness or musculoskeletal injury, hypertension where vigorous exercise was contraindicated, or cold intolerance.

Once medical clearance and informed consent were obtained, body composition was assessed via dual energy x-ray absorptiometry. Participants were then scheduled for 2 separate trials held at least 1 week apart to prevent heat acclimation. Participants were asked to refrain from alcohol use and exercise for 24 hours, and caffeine use for 12 hours prior to each trial. For

24 hours prior to their first trial, participants recorded their food/fluid intake on a standard diet log and were instructed to match their intake before their second trial. Prior to instrumentation, participants provided a small urine sample to verify euhydration prior to trials. Urine was measured via refractometry for specific gravity (Atago, Japan; USG). Participants also provided a nude body mass prior to each trial to further support euhydration (model 349KLX, Health-o-med, McCook, IL).

Instrumentation

Participants were provided with a heart rate (HR) strap to wear for the duration of exercise and treatment (Polar, Inc., Lake Success, NY, USA). A blood pressure cuff was placed on the upper arm and three ECG electrodes were attached (right and left subclavicular fossa, and right anterior abdominal line) to allow for arterial blood pressure to be measured by auscultation of the brachial artery via electrosphygmomanometry (Tango^{+}, SunTech, Raleigh, NC, USA). Participants inserted a rectal thermistor (Physitemp Instruments, Inc., Clifton, NJ, USA) 15cm beyond the anal sphincter for rectal temperature (T_{re}) measures throughout trials. Participants were educated on perceptual measures [rating of perceived exertion (RPE), thirst and thermal sensation, and perceived muscle pain] that were assessed throughout exercise and treatment.

<u>Exercise Protocol</u>

After instrumentation, participants entered an environmental chamber [(Can-Trol Environmental Systems, Markham, ON) 33.4 ± 0.8°C, 55.7 ± 1.9% relative humidity]. Participants then sat on a chair for 10 minutes followed by the collection of baseline values for T_{re}, blood pressure, HR, and perceptual measures. Immediately following baseline measurements, the blood pressure cuff and electrode leads were removed and participants moved to and began exercise on either a cycle or treadmill. Lead and cuff removal was completed to remove the connections that may get caught on exercise equipment during the exercise protocol for participant safety. During the first trial, exercise intensity, mode and duration was self-selected by participants and recorded by the research staff such that it was sufficient to elevate T_{re} to at least 39°C. This matched exercise protocol was repeated for the second trial, ensuring a match in metabolic heat production during exercise. T_{re} and HR were recorded continuously throughout exercise and cooling via computer (LabChart7, ADInstruments, Inc., Colorado Springs, USA) at 50Hz during exercise and treatment. Perceptual measures (RPE, thermal perception, and thirst sensation) were taken every 10 minutes during exercise. Exercise was immediately ceased if a participant began to experience signs/symptoms of exertional heat illness or their temperature reached 41°C. During exercise, participants were encouraged to consume water heated to 38°C ad libitum. Once participants reached a T_{re} of at least 39°C, they ceased exercise and moved to the cooling portion of the trial.

Treatment Protocol

A standardized transition of five minutes was utilized to simulate effective movement of an EHS patient to a treatment area. Participants moved to the treatment area inside the environmental chamber and assumed a semi-recumbent position on a standard tarp (8' x 10'), with a researcher holding the corners and edges of the tarp (minimum of 6 people). Prior to starting treatment, participants were re-instrumented with the BP cuff and leads, and pre-cooling perceptual measures were taken. The researchers elevated their respective corners of the tarp, forming a "taco" shape to begin treatment.

During TACO, 151L of ice water (2.1 ± 0.8°C) were poured on and around the subject using four 37L water coolers, ensuring that the head and upper chest of the participant were out of the water. Participants remained immersed for 15 minutes or until their T_{re} returned to 38.3°C

(~101°F). Following immersion, participants were assisted in exiting the tarp, toweled dry, and returned to sitting on a chair inside the environmental chamber for 30 minutes. During this latter portion of recovery, HR and T_{re} were recorded every 10 minutes. Participants then exited the chamber to towel completely dry and remove instrumentation.

During the CON trial, the participants remained in the tarp in the semi-recumbent position inside the environmental chamber for 15 minutes with no immersion. The participants then moved to the chair and sat inside the environmental chamber for 30 minutes at which time they toweled completely dry and removed instrumentation. For both treatments, physiological data (T_{re} and HR) were monitored continuously during and following treatment. Blood pressure was taken immediately pre- and post-cooling. Perceptual measures were taken at the beginning and end of treatment as well.

Cooling rate was calculated using the equation [(pre-treatment T_{re} – post-treatment T_{re}) / treatment time]. Blood pressure values were used to calculate mean arterial pressure (MAP) using the equation 1/3*Pulse Pressure + Diastolic Blood Pressure.

Data Analysis

Statistical analysis was completed using IBM SPSS Statistics v23.0 (IBM, Armonk, NY, USA). Analysis was done on data collected pre- and post-treatment for all measures using repeated measures ANOVA to assess the effects of treatment between trials. Cooling rates were analyzed using a paired t-test. An alpha of <0.05 was set a priori and any statistically significant values were run through post-hoc analysis with appropriate Bonferroni correction. Effect size (ES) was calculated using G*Power Version 3.1.9.2 (Universitat Kiel, Germany). As no differences between males and females were identified for any variable, data were combined for analyses. Results are presented as means ± standard deviations.

RESULTS

Twenty-four hour diet logs demonstrated no differences between trials (kcal: $t_{15}=-0.97;$ P=0.35; ES=0.24, protein: $t_{15}=-1.40;$ P=0.18; ES=0.35, carbohydrates: $t_{15}=-0.85;$ P=0.93; ES=0.02, fat: $t_{15}=-0.88;$ P=0.39; ES=0.22; data not shown). Hydration status was not different between trials with either body mass (t_{15} = 0.03; P=0.98; ES=0.01), or urine osmolality (t_{15} = -1.91; P=0.08; ES=0.48). Fluid consumption during exercise was not different between CON (0.26 ± 0.29 L) and TACO (0.19 ± 0.26 L; t_{12}=1.73; P=0.11; ES=0.48).

T_{re} exhibited an interaction of time and treatment ($F_{1,15}$ = 50.40, P < 0.001; partial η^2=0.77) as the pre-cooling time was similar for both conditions (CON 39.27 ± 0.26°C, TACO 39.30 ± 0.39°C: P=0.62; ES=-0.09) but was significantly lower post-cooling during TACO (38.10 ± 0.16°C) compared to CON (38.74 ± 0.38°C, P<0.001; ES=2.27). Cooling rate was significantly faster during TACO than CON (t_{15}=-8.84, P<0.001; ES=2.21; Figure 1). HR was not different between conditions ($F_{1,15}$ = 1.15, P=0.30; partial η^2=0.07) nor was there an interaction ($F_{1,15}$ = 3.29, P=0.09; partial η^2=0.18). However, HR decreased independent of treatment ($F_{1,15}$ = 182.52, P<0.001; partial η^2=0.92) from pre-cooling (158.8 ± 17 bpm) to end cooling (102.2 ± 11 bpm). Change in heart rate (ΔHR) from pre- to post-cooling was not different between TACO (-62 ± 22 bpm) compared to CON (-51 ± 19 bpm; $t_{15} = -1.81$, P=0.09; ES=0.45). There was an interaction of time and treatment for MAP ($F_{1,13}$ = 12.51, P=0.004; partial η^2=0.49; Figure 2) with end-cooling greater in TACO than in CON (P<0.001).

Thermal sensation exhibited an interaction of time and treatment ($F_{1,13}$ = 140.17, P<0.001; partial η^2=0.92) with responses lower post-cooling in TACO compared to CON (P<0.001; Figure 3). There was also an interaction of time and treatment for thirst ($F_{1,13}$ = 19.12, P<0.001; partial η^2=0.60; Figure 3). Muscle pain also had an interaction effect ($F_{1,13}$ = 14.48,

P=0.002; partial η^2=0.53) and was increased post-cooling in TACO compared to CON (P=0.007; Figure 3).

During post-cooling recovery, there was a significant interaction of time and treatment for T_{re} ($F_{3,42}$ =5.72; P=0.02; partial η^2=0.29; Figure 4). HR during post-cooling recovery was lower with TACO than CON regardless of time point ($F_{1,14}$ = 58.93, P < 0.001; partial η^2=0.81) and was decreased independent of treatment ($F_{3,42}$ = 16.55, P<0.001; partial η^2=0.54), with no interaction of treatment and time ($F_{3,42}$ = 2.40, P=0.08; partial η^2=0.15; Figure 4).

DISCUSSION

We found that using TACO for whole body cooling of hyperthermic individuals was significantly more effective than CON. Further, our data establishes that TACO provides a cooling rate previously deemed acceptable for the treatment of EHS victims.[10] This study demonstrates decreased body temperature, safe cardiovascular responses, and enhanced perceptual outcomes with TACO following exertional hyperthermia. Our data is important for athletic trainers working with military and athletic personnel who develop emergency action plans that must be executed in remote or restricted areas where traditional CWI with a tub may be difficult.

Though our water temperature (2.1 ± 0.8°C) was comparable to that of the coldest water used in other studies, our cooling rate was slightly less than CWI cooling seen elsewhere (up to 0.35°C·min^{-1}**)**.[8] This difference is likely due to the fact that our participants were only being immersed to the iliac crest, whereas the Proulx et al.[8] participants were immersed in 2°C water up to their clavicle. Even with the limitation that TACO is partial-body CWI, our cooling rate of

$0.14°C·min^{-1}$ would allow for safe cooling of EHS victims within a 30 minutes, making this an acceptable ($>0.078°C·min^{-1}$) modality for emergency treatment.[10]

For ethical reasons, we could not allow individuals to reach core temperatures indicative of EHS (>40.5°C). Importantly, there is strong evidence that hyperthermic study participants cool at similar rates compared to EHS patients when using CWI. A recent example of this point is data from 274 EHS patients, who were cooled with CWI following diagnosis at a mean rate of $0.22 \pm 0.11°C·min^{-1}$.[17] Cooling rates using CWI for hyperthermic subjects ranges from 0.129 to $0.35°C·min^{-1}$.[10] Cooling rates are similar in the literature between EHS victims and hyperthermic research participants.[10,15]

For field use, TACO has obvious benefits compared to a traditional CWI tub. Tarps can be folded and stored in medical kits with ease, and can cost as little as $15, whereas a stock tank costs ~$200. We found that 151L of ice water was sufficient to submerge participants at least up to the iliac crest with little variation in water temperature. This amount of water was chosen during pilot testing due to the fact that most venues have at least 4 coolers of ice water available in case of emergency. For use of this method in the field, we recommend to have at least six people to assist holding the tarp since 151L of water weighs ~150kg independent of the patients' body weight. As with all emergency action plans, it is recommended that medical staff practice this method before an actual emergency with all individuals that may be involved in emergency procedures at the venue. We found that standing close to the patient helps maintain water level, and allows oscillating the tarp efficient with repeated knee bends to maintain water circulation. While we did not quantify the amount of water circulation in the current study, the same researchers were used for each trial to ensure consistent oscillation. Furthermore, given our acceptable cooling rate, this provided sufficient movement to facilitate cooling.

Our cooling rates with TACO are slightly faster than those previously identified with constantly rotating towels or sheets for heat illness treatment.[16] Armstrong et al.[16] identified a mean cooling rate of $0.11°C·min^{-1}$ in seven EHS patients when continual rotation of ice soaked towels was utilized. There are other successful anecdotal reports of constant rotation of ice sheets in treating heat casualties in the military. However, this treatment option requires further research documentation to be considered evidence-based. One of the advantages of rotating ice-soaked towels or sheets is that treatment requires less cold water (~38L vs. 151L) in our TACO trial. This may increase feasibility in some instances where cold water is in short supply, however, it may also be a limiting factor in cooling rate. The more water in contact with the patients skin enhances cooling, and the less water utilized in treatment may compromise cooling efficiency.[10,12] Based on our data, TACO is recommended above ice sheet rotations because there is evidence to support its use. Future research should investigate and document the efficacy of ice sheet rotations.

Since our participant group consisted of similar body types, it is recommended for future studies to use this method on a more heterogeneous sample population to assure effectiveness on all body types and to provide the best recommendations for use in the field. For example, previous research has shown that differences in body surface area (BSA) and body surface area to lean body mass ratio (BSA/LBM) affect cooling rates for hyperthermic individuals.[9,17] Since CWI relies on conductive and convective heat loss, it follows that a greater BSA allows for more contact with the cold water, and therefore a greater amount of heat loss can be achieved. Even though individuals with a larger BSA relative to BMI may have greater adiposity, studies also found that adiposity has a limited effect on cooling rate.[17]

Heart rate responses to water immersion following exercise vary from non-significant decreases in thermoneutral water to significant decreases in cold water (<16°C).[18,19] Though our ΔHR was not different between CON and TACO, the greater MAP (Figure 2) in TACO post-cooling indicates a better maintenance of cardiac function during TACO than control. During CON, since the participants were semi-recumbent and not moving for 15 minutes, blood likely pooled in the lower extremities and delayed recovery. Furthermore, Kenny et al[20] demonstrated reductions in sweating and skin blood flow while esophageal temperature was still elevated following exercise. These reductions occur due to nonthermal contributions leading to impaired heat loss. As our MAP decreased similarly at the end of treatment, is possible that these perturbations in heat loss mechanisms may have led to the slower cooling rates in our CON trial.

Our perceptual measures provided insight into how our participants felt during cooling. Thirst was rated lower post-cooling in TACO, which is likely due to the maintenance of blood pressure and circulation during immersion. Because we used an extreme water temperature, the findings of decreased thermal sensation with TACO compared to CON were expected. Our identified increase in muscle pain with cooling may be a result of our participants' difficulty differentiating between muscular and cutaneous pain sensation caused by the water temperature. Some of our participants began to shiver during cooling as well, which may have increased muscular pain.

CONCLUSIONS

The purpose of this study was to examine the cooling effectiveness of TACO following exercise-induced hyperthermia. With the resulting cooling rate of $0.14 \pm 0.06°C \cdot min^{-1}$, TACO is an acceptable method of reducing an individual's core temperature in an appropriate amount of time for emergency treatment of EHS. Though CWI in a traditional tub remains the gold standard for

EHS treatment, TACO is recommended for use in emergency action plans for remote venues or in situations where the purchase, or use, of a CWI tub is not feasible.

REFERENCES

1. Carter III R, Cheuvront SN, Williams JO, et al. Epidemiology of hospitalizations and deaths from heat illness in soldiers. *Med Sci Sports Exerc.* 2005;37(8):1338-1344.

2. Bedno SA, Urban N, Boivin MR, Cowan DN. Fitness, obesity and risk of heat illness among army trainees. *Occup Med (Lond)*. 2014;64(6):461-467.

3. Kerr ZY, Casa DJ, Marshall SW, Comstock RD. Epidemiology of exertional heat illness among US high school athletes. *Am J Prev Med*. 2013;44(1):8-14.

4. Yard EE, Gilchrist J, Haileyesus T, et al. Heat illness among high school athletes—United states, 2005–2009. *J Saf Res*. 2010;41(6):471-474.

5. Armstrong LE, Johnson EC, Casa DJ, et al. The American football uniform: Uncompensable heat stress and hyperthermic exhaustion. *J Athl Train*. 2010;45(2):117-127.

6. Casa DJ, DeMartini JK, Bergeron MF, et al. National Athletic Trainers' Association position statement: Exertional heat illnesses. *J Athl Train*. 2015;50(9):986-1000.

7. Heled Y, Rav-Acha M, Shani Y, Epstein Y, Moran DS. The "golden hour" for heatstroke treatment. *Mil Med*. 2004;169(3):184-186.

8. Costrini A. Emergency treatment of exertional heatstroke and comparison of whole body cooling techniques. Med Sci Sports Exerc. 1990;22(1):15-18.

9. Proulx CI, Ducharme MB, Kenny GP. Effect of water temperature on cooling efficiency during hyperthermia in humans. *J Appl Physiol*. 2003;94(4):1317-1323.

10. Friesen BJ, Carter MR, Poirier MP, Kenny GP. Water immersion in the treatment of exertional hyperthermia: Physical determinants. *Med Sci Sports Exerc*. 2014;46(9):1727-1735.

11. McDermott BP, Casa DJ, Ganio MS, et al. Acute whole-body cooling for exercise-induced hyperthermia: A systematic review. *J Athl Train*. 2009;44(1):84-93.

12. Casa DJ, McDermott BP, Lee EC, Yeargin SW, Armstrong LE, Maresh CM. Cold water immersion: The gold standard for exertional heatstroke treatment. *Exerc Sport Sci Rev*. 2007;35(3):141-149.

13. Mazerolle SM, Pinkus DE, Casa DJ, et al. Evidence-based medicine and the recognition and treatment of exertional heat stroke, part II: A perspective from the clinical athletic trainer. *J Athl Train*. 2011;46(5):533-542

14. Demartini JK, Casa DJ, Stearns R, et al. Effectiveness of cold water immersion in the treatment of exertional heat stroke at the falmouth road race. *Med Sci Sports Exerc*. 2015;47(2):240-245.

15. Hadad E, Moran DS, Epstein Y. Cooling heat stroke patients by available field measures. *Intensive Care Med*. 2004;30(2):338-338.

16. Armstrong LE, Crago AE, Adams R, Roberts WO, Maresh CM. Whole-body cooling of hyperthermic runners: comparison of two field therapies. *Am J Emerg Med.* 1996;14(4):355-358.

17. Lemire BB, Gagnon D, Jay O, Kenny GP. Differences between sexes in rectal cooling rates after exercise-induced hyperthermia. *Med Sci Sports Exerc*. 2009;41(8):1633-1639.

18. Wilcock IM, Cronin JB, Hing WA. Physiological response to water immersion. *Sports medicine*. 2006;36(9):747-765.

19. DeMartini JK, Ranalli GF, Casa DJ, et al. Comparison of body cooling methods on physiological and perceptual measures of mildly hyperthermic athletes. *J Strength Cond Res*. 2011;25(8):2065-2074.

20. Kenny GP, Gagnon D, Jay O, McInnis NH, Journeay WS, Reardon FD. Can supine recovery mitigate the exercise intensity dependent attenuation of post-exercise heat loss responses? *Appl Physiol Nutr Metab.* 2008;33(4):682-689.

LEGENDS TO FIGURES

Figure 1. Cooling rate responses to treatment. Abbreviation: CON, control, TACO, tarp assisted cooling with oscillation. [a]Indicates significantly greater than CON (t_{15}=-8.84, P<0.001; ES=2.21).

Figure 2. A) Heart rate responses pre- and post-treatment for both trials. B) Mean arterial pressure (MAP) measures pre- and post-treatment for both trials. Abbreviation: CON, control, TACO, cold-water immersion. [a]Indicates a significant difference between pre- and post-cooling, regardless of trial (P<0.001). [b]indicates a significant difference between CON and TACO (P<0.05).

Figure 3. Perceptual measures pre- and post-treatment. [a]Indicates a significant difference between CON and TACO (P < 0.05).

Figure 4. A) Heart rate responses during the post-cooling recovery. B) Rectal temperature responses during the post-cooling recovery. [a]Indicates significant difference from CON (P <

0.05). [b]Indicates significant difference from 0 minutes ($P < 0.05$). [c]Indicates significant difference from 10 minutes ($P < 0.05$).

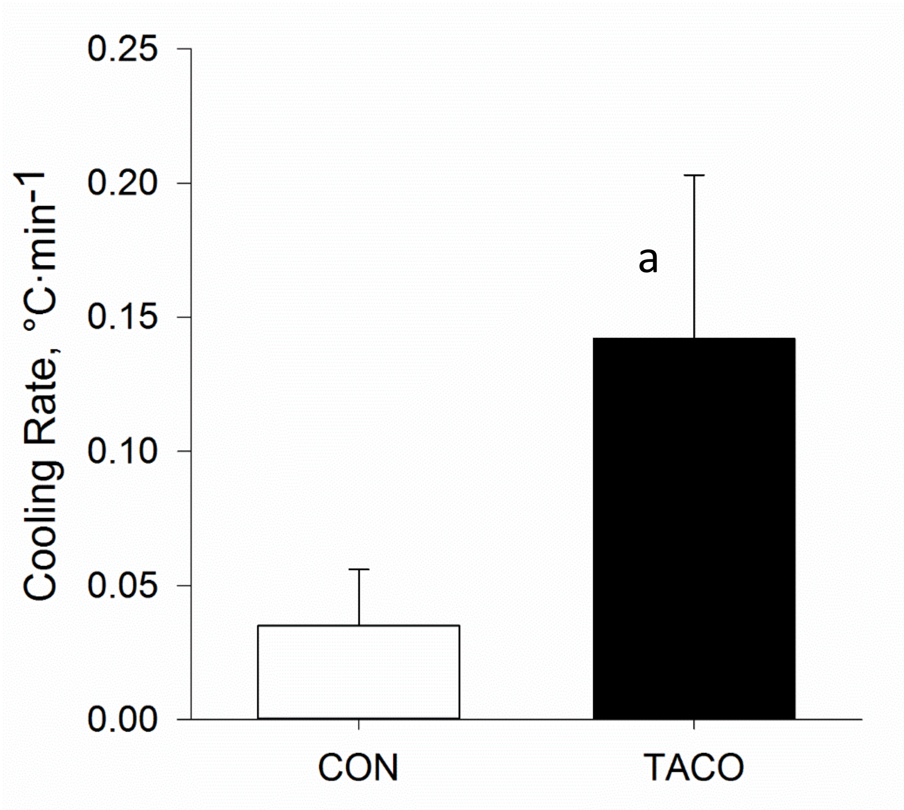


Figure 1.

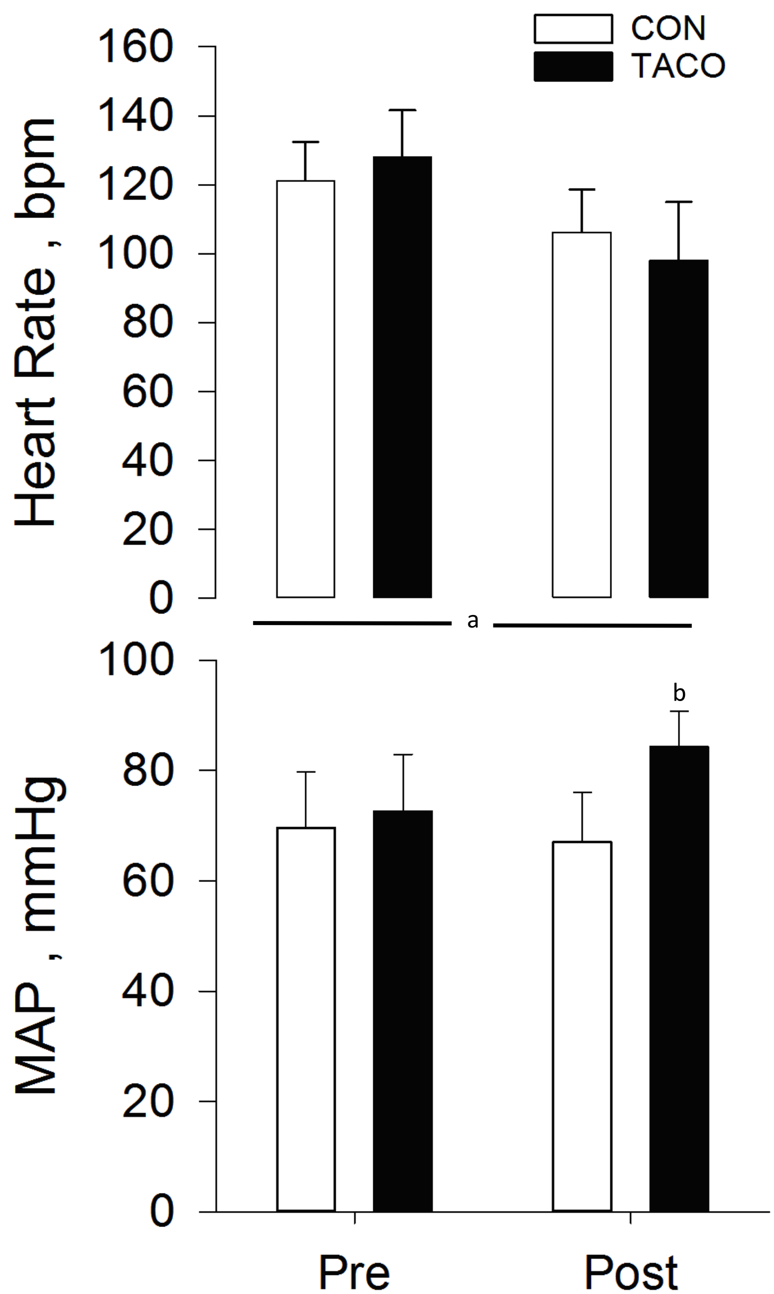
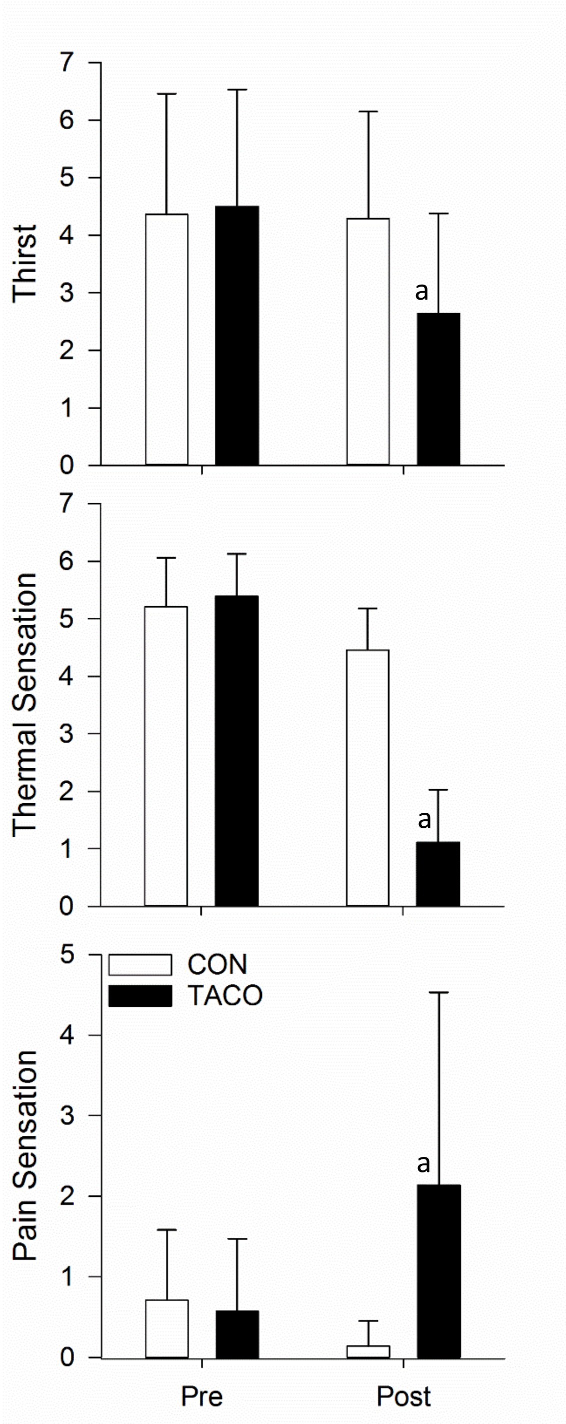
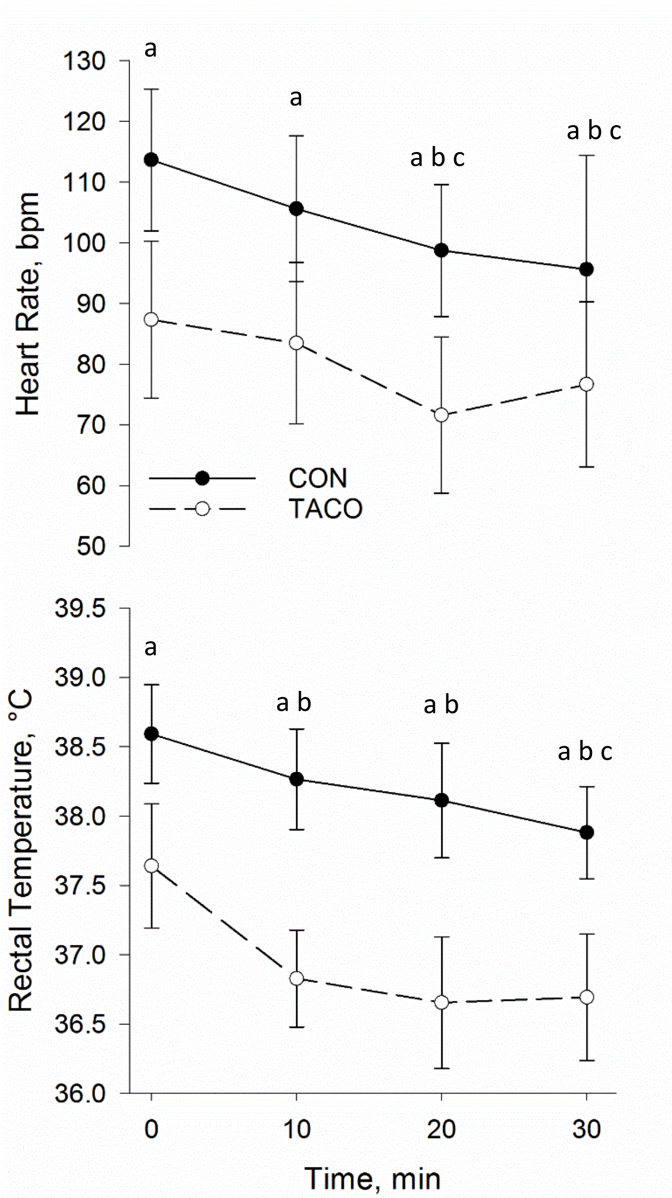

CON
TACO
Heart Rate , bpm
160
140
120
100
80
60
40
20
0
a
MAP , mmHg
100
80
60
40
20
0
b
Pre
Post

Figure 2.



Thirst
Thermal Sensation
Pain Sensation
CON
TACO
a
a
a
Pre
Post

Figure 3.



130
120
110
100
90
80
70
60
50
Heart Rate, bpm
a
a
a b c
a b c
CON
TACO
39.5
39.0
38.5
38.0
37.5
37.0
36.5
36.0
Rectal Temperature, °C
a
a b
a b
a b c
0
10
20
30
Time, min

Figure 4.

V. Discussion and Conclusion

The purpose of this study was to examine the effectiveness of TACO in reducing core temperature of individuals experiencing exercise-induced hyperthermia. The resulting cooling rate of $0.14 \pm 0.06 °C \cdot min^{-1}$ shows this method is faster than control, and would be acceptable for use in cooling victims of EHS in the field. It is recommended to be included in an emergency action plan for venues that have monetary or spatial restrictions. The 40 gallons of water used in this protocol should be easily found at most venues, and it should not be difficult to recruit and instruct the required assistants. Oscillation of the water is an important component of TACO and provides many benefits including maintaining blood pressure during cooling and decreasing thirst. These outcomes demonstrate that TACO can be a valuable tool in aiding recovery.

VI. Appendix

IRB Approval Letter

UNIVERSITY OF ARKANSAS

Office of Research Compliance
Institutional Review Board

September 15, 2014

MEMORANDUM

TO:	Brendon McDermott, Katherine Luhring, Jeffrey Bonacci, Nicole Moyen, Jenna Burchfield, Cory Butts, Cody Smith, Matthew Tucker, JD Adams, Matthew Ganio
FROM:	Ro Windwalker IRB Coordinator
RE:	New Protocol Approval
IRB Protocol #:	14-08-063
Protocol Title:	*The Cooling Effectiveness of a Modified Cold Water Immersion Method following Exercise in a Hot Environment in Euhydrated and Dehydrated Individuals*
Review Type:	☐ EXEMPT ☐ EXPEDITED ☒ FULL IRB
Approved Project Period:	Start Date: 09/15/2014 Expiration Date: 09/09/2015

Your protocol has been approved by the IRB. Protocols are approved for a maximum period of one year. If you wish to continue the project past the approved project period (see above), you must submit a request, using the form *Continuing Review for IRB Approved Projects*, prior to the expiration date. This form is available from the IRB Coordinator or on the Research Compliance website (http://vpred.uark.edu/210.php). As a courtesy, you will be sent a reminder two months in advance of that date. However, failure to receive a reminder does not negate your obligation to make the request in sufficient time for review and approval. Federal regulations prohibit retroactive approval of continuation. Failure to receive approval to continue the project prior to the expiration date will result in Termination of the protocol approval. The IRB Coordinator can give you guidance on submission times.

This protocol has been approved for 60 participants. If you wish to make *any* modifications in the approved protocol, including enrolling more than this number, you must seek approval *prior to* implementing those changes. All modifications should be requested in writing (email is acceptable) and must provide sufficient detail to assess the impact of the change.

If you have questions or need any assistance from the IRB, please contact me at 210 Administration Building, 5-2208, or irb@uark.edu.

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