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The Influence of Head Cooling Combined with Various Cooling Modalities on Cooling Rate After Exercise in the Heat

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**The Influence of Head Cooling Combined with Various Cooling Modalities on Cooling
Rate After Exercise in the Heat**

Jennifer L. Hyde

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Master of Science Thesis

The Influence of Head Cooling Combined with Various Cooling Modalities on Cooling Rate
After Exercise in the Heat

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Abstract

The Influence of Head Cooling Combined with Various Cooling Modalities on Cooling Rate After Exercise in the Heat

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Context: Various body-cooling modalities after exercise or between exercise bouts have been shown to decrease body temperature. The addition of head cooling (HC) to other commonly used cooling modalities may aid in reducing thermal strain. **Objective:** To determine the efficacy of head cooling on rectal temperature (T_{re}) compared to commonly implemented cooling modalities. **Design:** Randomized, counterbalanced, crossover design. **Setting:** Research laboratory. **Participants:** Fourteen recreationally active individuals (mean \pm SD: male, $n=7$, female, $n=7$; age=25 \pm 4y; height=171 \pm 9cm; body mass=70.8 \pm 8.3kg; percent body fat=21.2 \pm 7.6%). **Intervention:** Participants completed six bouts of treadmill exercise (55.2 \pm 12.2min) in a hot environment (38.5 \pm 1.5°C, 37.5 \pm 7.6%RH) until one of the following occurred: T_{re} reached 39.75°C, 80 minutes of exercise, or the participant requested to stop. Exercise sessions were followed by body cooling until T_{re} reached 38.00°C or for a maximum of 10 minutes. Cooling treatments (HC, cold-water immersion (CWI), forearm ice towels (IT), CWI+HC, IT+HC, and passive rest) were performed in a thermoneutral environment (22.4 \pm 1.6°C, 32.1 \pm 12.3%). Participants then returned to the heat, equilibrated for 10 minutes, and conducted approximately 20 minutes of performance tasks. At 40 minutes post-cooling initiation, T_{re} was again obtained. **Main outcome measures:** Heart rate (HR) was measured before (PRE), after (POST) exercise while T_{re} was additionally measured immediately following performance tasks. Differences between cooling methods were determined using a repeated measures one-way ANOVA with pre-planned dependent t-tests. An *a priori* alpha level was set at 0.05. **Results:** POST HR (168 \pm 18 beats per minute), and POST T_{re} (39.17 \pm 0.46°C) were similar between groups ($p>0.05$). Upon initiation of cooling, T_{re} was also similar across groups (39.35 \pm 0.48°C, $p>0.05$). The cooling rate for passive rest (0.07 \pm 0.02°C \cdot min⁻¹) was lower than all other cooling conditions ($p<0.014$) except HC (0.09 \pm 0.04°C \cdot min⁻¹; $p=0.073$). Cooling rate for CWI+HC (0.13 \pm 0.07°C \cdot min⁻¹) compared to HC (0.09 \pm 0.04°C \cdot min⁻¹) trended towards significance ($p=0.052$). The addition of head cooling to CWI did not result in an enhanced cooling rate compared to CWI alone (0.11 \pm 0.02°C \cdot min⁻¹, $p=0.425$). The addition of head cooling to IT did not result in an enhanced cooling rate (0.13 \pm 0.07°C \cdot min⁻¹) compared to IT (0.11 \pm 0.05°C \cdot min⁻¹, $p=0.215$). Total drop in T_{re} after 40 minutes from the beginning of cooling for CWI and CWI+HC was similar (3.60 \pm 1.02°C, 3.74 \pm 0.95°C, respectively, $p>0.05$) and resulted in lower T_{re} than all other conditions ($p<0.05$). **Conclusions:** Adding head cooling to common cooling modalities did not provide additional cooling benefits. Cooling rate was greater for all cooling methods compared to passive rest, with the exception of HC. Cooling with CWI or CWI+HC resulted in lasting cooling effects after 40 minutes, which is likely due to T_{re} after-drop.

Chapter I. Review of the Literature

Background on Thermal Stress

Heat stroke has been recognized as one of the oldest known medical conditions and is the most serious and life threatening of all heat illnesses.¹ Instances of exertional heat stroke (EHS) have been recorded dating back to biblical times in laborers and warfighters.² It is vital to recognize that EHS is the most serious and life threatening of all heat illnesses.¹ Throughout history, the prevention, recognition, and treatment methods for EHS have changed dramatically. The changes in the standards of care for EHS are largely responsible for the difference between life and death. From the primal beginnings of bloodletting recommended by Galen¹ for the treatment of EHS, to the modern day “Gold Standard,” of cold-water immersion (CWI),³ it has been observed that EHS is 100% survivable with proper recognition and treatment.^{1,4} The emphasis here arises from the use of proper treatment. While new body cooling modalities are constantly coming to surface and requiring investigation, it is more important to recognize that CWI maintains to have the greatest overall cooling rate and should be the treatment in cases of EHS. Other body cooling modalities may be beneficial for mitigating the overall rate of rise of body temperature, but certainly do not serve as a replacement for CWI as the gold standard of treatment in EHS patients.

A number of specific topics are relevant when analyzing heat stress as it relates to participation in physical activity. Throughout this literature review, several of these key topic areas will be discussed. In order to develop a clear understanding of heat stress as it relates to physical activity, the physiological changes that occur within the body during exercise in the heat must first be addressed. Once this basic understanding of thermal physiology has been developed, a more in depth analysis of EHS can occur. In the event EHS does happen, a

thorough understanding of the “gold standard” of care, both recognition and treatment, is indicated. Attention to additional treatment methods for EHS will also be assessed, in addition to the use of cooling modalities for maintaining athletic performance. Special considerations include the implications of protective equipment and clothing and their role in heat stress.

Physiological Changes to Exercise in the Heat

A number of physiological changes are associated with exercise in the heat. Some important topics to consider here are the physiological responses associated with increases in cardiovascular and thermoregulatory strain. Cardiovascular and thermoregulatory strain combine to have negative implications for exercise performance. It is also important to recognize that each one of the body’s physiological mechanisms is impacted by hydration status.^{5,6} The magnitude of dehydration determines the degree of negative impact on systemic involvement.

Heat Balance and Thermoregulation

Thermoregulation has been defined as an interaction occurring between the CNS, cardiovascular system, and the skin to maintain a body temperature of 37°C.⁷⁻¹⁰ Body temperature is controlled by the hypothalamus, and it is here that the core temperature is regulated around a set point.^{7,8,11-14} The body produces significant amounts of heat via metabolic processes. 60-70 kcal·h⁻¹ are produced for a fasting adult at rest primarily by way of internal organs.¹⁵ When an individual partakes in intense exercise, more than 90% of metabolic heat production occurs in the working muscle and can increase to nearly 1000 kcal·h⁻¹.¹⁵ In the exercising individual, working muscles produce increased metabolic heat through the repetitive contractions required to perform the exercise.¹⁶ In an individual who is able to appropriately thermoregulate a balance within the exercising body is established between the

amount of heat produced metabolically and that which is lost through conduction, convection, evaporation, and radiation.^{12,17} The heat balance equation illustrates this concept^{12,17} where:

- S= Amount of stored heat
- M= Metabolic heat produced
- R= Heat gained or lost via radiation
- K= Conductive heat gained or lost
- C_v= Convective heat gained or lost
- E= Evaporative heat lost

$$S = M \pm R \pm K \pm C_v - E$$

Heat can further be gained or lost through four mechanisms: radiation, conduction, convection, and evaporation. In radiation, energy is transferred to or from the body by way of electromagnetic radiation from higher to lower surfaces.^{7,8,12,18,19} Conduction involves the transfer of heat from warmer to cooler objects via physical contact.^{12,18-21} Convection is the process by which heat moves from to or from the body through a moving fluid or air.^{7,12,18,19,21} Evaporation occurs through the sweating mechanism and serves as the most efficient method the body loses heat.^{13,18,22} The degree to which sweat is able to evaporate from the skin is dependent on the saturation of the surrounding air with water (humidity) and the velocity of that air.²³⁻²⁵

Cardiovascular Changes, Cardiovascular Drift and Exercise in the Heat

Specific adjustments have been observed when the body engages in exercise in hot conditions. An increase in heart rate coupled with a decrease in stroke volume and concurrent decrease in cardiac output characterize the cardiovascular alterations that occur during exercise in the heat.²⁶ Existing research has demonstrated that increased thermal strain with associated elevations in body and skin temperature during exercise in the heat subsequently increase

cardiovascular strain.^{27,28} Heart rate increases by approximately 3 beats per minute with every 1% of body mass lost.^{29,30} Existing evidence also states that for every 1% of body mass lost via fluid losses in sweat, body temperature increases by a factor of 0.22°C (0.5°F).³¹ As a result of these changes, decrements in performance and decreases in central blood volume have been observed. Furthermore, each one of the physiological mechanisms of the body is impacted by hydration status; however, the degree of systemic involvement is directly related to the level of hypo or hyperhydration.^{5,6} (See Figure 1)

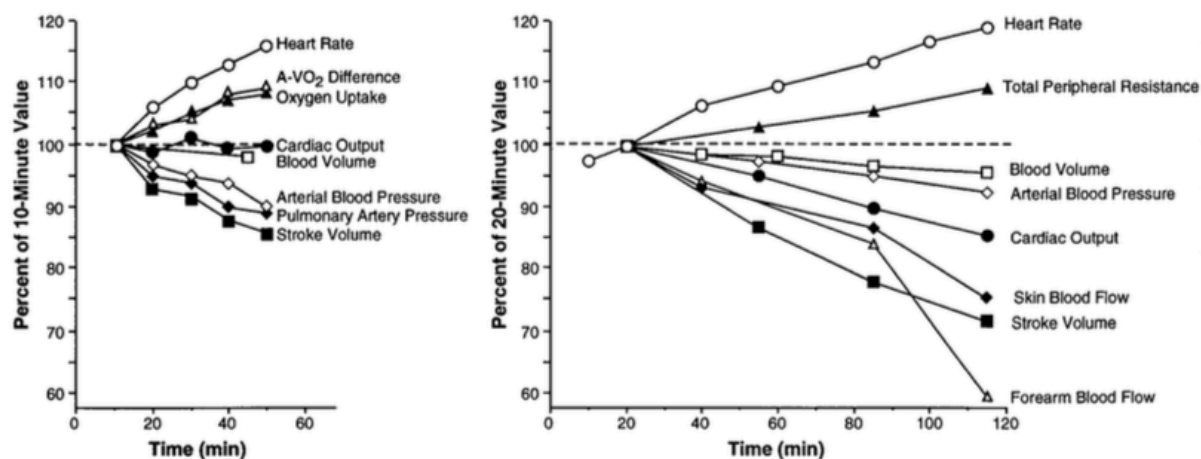


Figure 1-Coyle et al. Cardiovascular Drift During Prolonged Exercise: New Perspectives. *Exercise and Sports Sciences Review*. 2001; 21(2):88-92

An important factor to consider when assessing cardiac function and exercise in the heat is the sweating mechanism. As the body attempts to thermoregulate via the sweating mechanism, fluid is lost from within the body. The rate at which the body achieves a fluid deficit is related to numerous factors. These factors include exercise intensity, environmental conditions, and clothing or equipment worn by the exercising individual.³² It should be noted that dehydration of the body prior to exercise by 1-2% has been shown to have negative effects on aerobic performance and the physiological functions of the body.³²⁻³⁴ Additionally, in the event an

athlete's level of hypohydration increases to greater than 3% of their body weight, anaerobic performance can be hindered, physiological disruptions continue to escalate, and subsequently increase the risk of suffering from an exertional heat illness.³² Cardiovascular strain in particular is increased with dehydration and exercise in the heat. (See Figure 2)

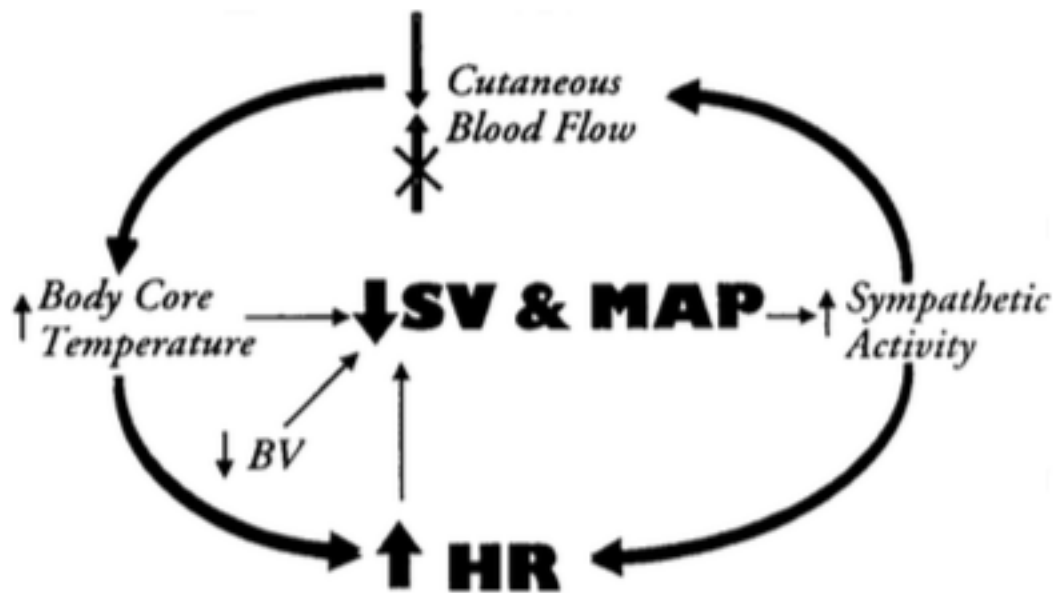


Figure 2-Coyle et al. Cardiovascular Drift During Prolonged Exercise: New Perspectives. *Exercise and Sports Sciences Review*. 2001; 21(2):88-92

Athletes frequently experience dehydration and this problem may occur more readily in the event an athlete engages in an exercise session when they are already hypohydrated.³² Specific attention should also be given to the environmental conditions at the time of exercise. The wet bulb globe temperature (WBGT) takes into account multiple environmental factors including wind speed, ambient temperature, relative humidity, and radiation from the sun.³⁵ By taking these four factors into account, a more acute assessment of environmental heat stress can be ascertained. High relative humidity conditions, which are frequently present during the summer months, serves as an extrinsic factor possessing the ability to increase an athlete's risk of suffering an exertional heat illness. Up to 80% of heat losses occur via evaporation during

exercise in warm and humid conditions.³² In the event exercise occurs during hot and dry conditions, it is possible for evaporation to account for as much as 98% of body cooling.³⁶ When dehydration is coupled with high sweat rates and high relative humidity, evaporative heat losses are minimized.³² Heavier sweating induced by hot and humid conditions results in sweat dripping off the body that is completely ineffective at removing heat from the body. Furthermore, this perpetuates large fluid loss, further resulting in increased body temperature.³⁷ This combination has the potential to yield swift increases in body temperature.³²

Exercise Performance

It has been established that once body temperature reaches approximately 38-40°C,³⁸⁻⁴⁸ fatigue begins to manifest in addition to increasing the risk of potential health and safety issues. Hyperthermia can have an impact on muscular endurance, the metabolism of carbohydrates, blood pooling in the extremities, the delivery of oxygen throughout the body and many other functions related to the body's ability to exercise in the heat.^{33,49} The observed decrease in time to volitional fatigue in the heat is considered to occur as a result of the increased body temperature which provokes a behavioral response further leading to the conscious decision to stop exercising.⁵⁰ Worth considering are two theories addressing why decreases in performance are observed in hyperthermic individuals. These theories are the critical limiting core temperature theory and central fatigue theory.

Critical Limiting Core Temperature Theory

The critical limiting core temperature theory and attenuation in central nervous system (CNS) drive leading to premature fatigue acts as a form of neuro-protection during exercise in the heat.⁵⁰ The notion of a critical limiting temperature in exercise has been observed in a range of mammals exercising in 25-35°C conditions.⁵¹⁻⁵⁴ Furthermore, the onsets of these observations

occurred when exercise duration has approached exhaustion with a body temperature of 40°C.⁵⁵⁻
⁵⁷ Nielsen et al.⁵⁵ demonstrated that both acclimated and non-acclimated individuals stopped exercising at the same body temperature. Hyperthermia as a result of exercise elicits a range of physiological responses including increases in heart rate, respiratory rate, muscle temperature, and muscle blood flow. These responses, coupled with the inability of the body to remove heat at the same rate at which it is gained yields voluntary termination of exercise and associated decreases in motivation.⁵⁸ The decline in CNS activation when the body experiences exercise-induced hyperthermia is postulated to occur because of the action of increasing temperature to the brain.⁵⁹ Additionally, the increase in brain temperature may affect the afferent signals from the skeletal muscle and other organs.⁵⁹ The critical limiting core temperature theory has been further supported by studies utilizing pre-cooling techniques. In these studies, it was concluded that a decreased thermal strain as a result of pre-cooling improved exercise time but resulted in similar core temperature at exercise termination, supplementing the theory that a critical body temperature threshold largely determines exercise termination.^{58,60}

Central Fatigue Theory

The central fatigue theory examines several physiological mechanisms in the body paying special attention to alteration in the CNS that serve as a gateway to impaired cardiovascular function.^{61,62} Changes in cardiovascular function give rise to reductions in blood oxygen delivery resulting in decreased aerobic capacity in the working skeletal muscles.^{63,64} Together, these factors lead to peripheral fatigue and the eventual termination of exercise.^{63,64} These physiological responses are of particular relevance during exercise in the heat. CNS function showcases its prominent role in limiting exercise during exercise in hot conditions, often when the body temperature rises above 40°C.^{63,65} It is at this juncture that oxygen is not

sufficiently transported to the exercising muscles during high-intensity exercise and cardiac output decreases. Numerous studies have been conducted supporting the notion that there is a body temperature at which humans will cease voluntary exercise.^{45,55,56,66,67} This critical temperature for the brain and body refers to the point at which a specific safety mechanism exists to protect the brain from devastating thermal injury.^{45,55}

It is clear that several mechanisms for limiting exercise exist in an effort to protect the body and brain from thermal injury. Other limiting factors such as training status, exercise intensity, internal and external motivation should also be considered as contributing factors.⁶⁸

Exertional Heat Stroke

The most important factor in ensuring survival from an episode of EHS is prompt recognition and treatment using evidence based practice. Current evidence states that the standard of care in the treatment of EHS is cold-water immersion (CWI).^{3,15} As a result of the current standards, CWI should maintain to be the treatment standard, and head cooling is not meant to serve as replacement for EHS treatment. Ensuring proper action is taken in the treatment of EHS; careful consideration must be taken in order to have the ability to properly treat patients. Appropriate recognition of EHS requires obtaining an appropriate measure of deep body temperature. Rectal temperature is the most accurate way to monitor body temperature in the field setting.⁶⁹ An athletic trainer should never rely on oral, axillary, or tympanic methods of temperature measurement. A delay in appropriate treatment of EHS or the utilization of a modality with a slower cooling rate will drastically increase the risk of fatality or associated morbidity.³

Diagnosis of EHS is determined by a body temperature $>40^{\circ}\text{C}$ (104°F) and CNS dysfunction. CNS dysfunction often serves as the first indicator of EHS.¹⁵ It should be noted

that CNS dysfunction is related to a general encephalopathy as opposed to neurological disruptions tied to cranial nerves.³⁷ A number of symptoms characterize the neurological disruptions associated with EHS. These symptoms include but are not limited to drowsiness, irrational behavior, disorientation, seizures, confusion, violent outbursts, aggressive behavior, irritability, loss of consciousness, and coma.^{15,37}

Predisposing Factors

There are a number of intrinsic and extrinsic risk factors that predispose an individual to EHS. EHS is a unique condition because individuals who are in a good state of health may still fall victim to this fatal condition.¹ This condition is fairly rare, however, it has been documented to occur as frequently as 1 in 1000 participants at some athletic events.^{70,71}

Among the intrinsic factors contributing to EHS are hydration status, heat acclimatization status, athlete education, access to appropriate medical care, sleep loss, prior history of exertional heat illness, certain medications and internal motivation.⁷² Extrinsic factors that contribute to EHS are environmental conditions, access to hydration, environmental conditions, appropriate rest periods, and protective equipment.⁷²

A combination of intrinsic and extrinsic factors can present simultaneously which increases one's predisposition for EHS. Rav-acha et al.⁷³ looked at six specific cases of EHS and determined the intrinsic and extrinsic factors present at the time of injury. Each of the evaluated cases presented with similar predisposing factors demonstrating the frequent presence of intrinsic and extrinsic factor as they relate to cases of EHS. For example, five out of the six cases included poor physical fitness and sleep deprivation as predisposing factors in fatal cases. Sleep deprivation may occur as a result of extrinsic forces such as with acts of war or during military training. As a result of the numerous factors that are often present concurrently during a case of

EHS, it is vital for the medical professional to utilize a multifaceted approach for the prevention of EHS.

Recognition

A number of key steps are necessary for the appropriate treatment of EHS. First and foremost, a rectal temperature should be obtained if possible.¹⁵ This will allow the medical professional to appropriately differentiate between EHS and heat exhaustion.¹⁵ CNS status should be evaluated for any potential changes, as CNS function is largely distorted during EHS.

¹⁵ A proper diagnosis of EHS will allow the medical professional the opportunity to engage in appropriate treatment as quickly as possible. A proper diagnosis can often be difficult to achieve to the complexity of signs and symptoms and they way they often overlap with other life-threatening conditions. Casa et al. represented this in Table 1. Ultimately proper recognition of EHS is predicated upon the presence of CNS dysfunction and a core body temperature of 104° or higher.

Table 1-Casa et al. Athletic Training and Sports Health Care. 2009; 1(4):144-146.

TABLE

Preventing Sudden Death in Sport: A Potentially Complex Overlap of Signs and Symptoms of Common Causes of Death ^a										
	EXERTIONAL HEAT STROKE	HEAT CRAMP ^b	HEAT SYNCOPE ^b	EXERCISE HEAT EXHAUSTION ^b	EXERTIONAL HYPONATREMIA	EXERTIONAL SICKLING	HEAD INJURY	CARDIAC ^c	RESPIRATORY ^d	SHOCK
CNS dysfunction ^e	X		X	X	X	X	X	X	X	X
Dizziness	X		X	X			X	X	X	
Drowsiness	X				X		X			X
Fatigue	X	X	X	X	X	X	X	X	X	X
Headache	X			X	X		X			
Light-headedness			X	X	X		X	X		X
Staggering	X			X	X	X	X	X	X	
Syncope	X		X	X				X	X	
Tunnel vision			X					X		
Personality changes ^f	X			X	X		X			
Lethargy					X		X	X	X	X
Core body temperature usually <40°C		X	X	X	X	X	X	X	X	X
Core body temperature >40°C immediate postincident	X									
Cool, clammy skin				X				X		X
Hot and wet or dry skin	X	X	X	X	X	X				
Pale skin			X	X				X		X
Cerebral edema					X		X			
Chills				X						X
Decreased pulse			X					X	X	X
Decreased urine output	X			X	X					
Dehydration	X	X	X	X		X				
Diarrhea	X			X						
Hyperventilation	X			X				X	X	X

Treatment

Prompt and appropriate treatment of this potentially fatal condition is required to ensure survival with the greatest chance for a positive patient outcome. The importance of appropriate medical care at athletic functions is paramount to successful treatment of EHS. Furthermore, the most important goal in the treatment of EHS is reducing the body's temperature to below 40°C within 30 minutes.^{74,75} Lowering the body temperature to below 40°C within the first 30 minutes of collapse from EHS has shown that EHS is 100% survivable.^{15,70,76} Body temperature above this threshold is deleterious to the human body as the proteins in the cells and tissues begin to denature and breakdown. It has been widely documented that the mortality rate of EHS is positively correlated to the amount of time the body spends above this critical threshold.^{36,77,78} In

order to avoid further organ and tissue damage, rapid, whole body cooling by an effective cooling modality is essential.^{79,80} An effective cooling modality should provide a cooling rate of greater than or equal to $0.1^{\circ}\text{C}\cdot\text{min}^{-1}$.³ (See Figure 3).

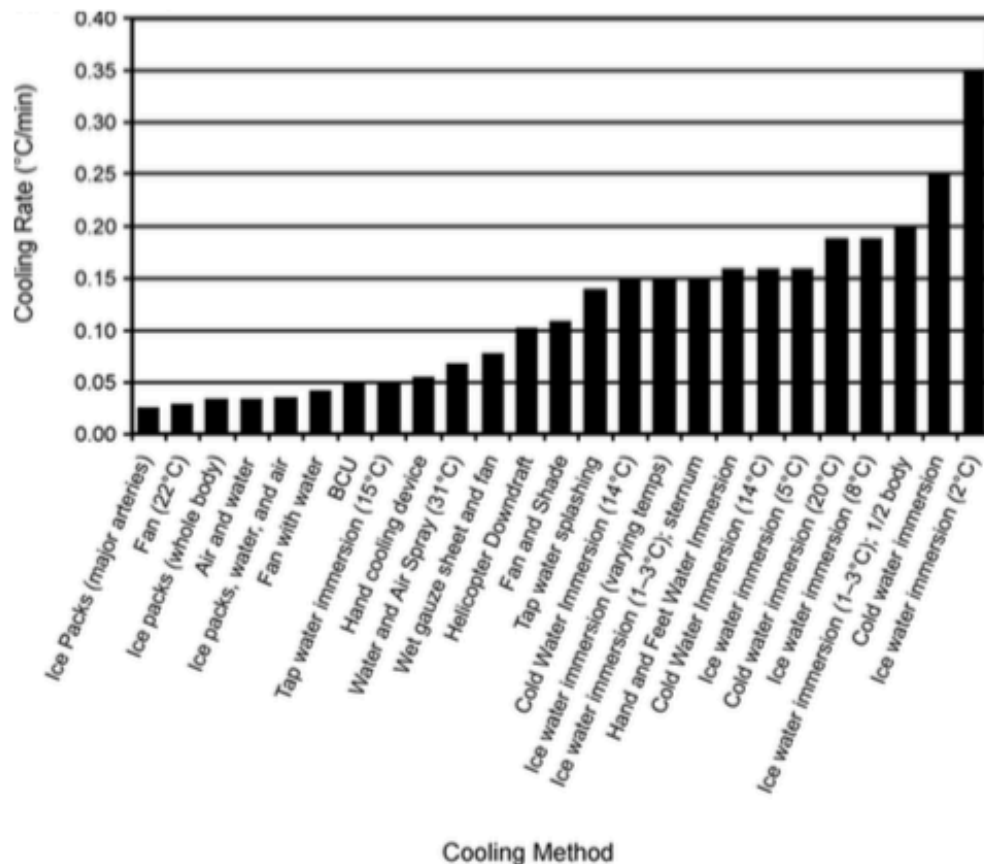


Figure 3-Casa et al. Cold-water Immersion: The Gold Standard for Exertional Heat Stroke Treatment. *Exercise and Sport Sciences Reviews*. 35(3):141-149, 2007.

Misconceptions Surrounding Cold-Water Immersion

Recent controversy has ensued over the efficacy of CWI and whether it should be utilized as the “gold standard” for EHS treatment. Among the primary concerns of medical professionals regarding CWI is the worry of causing the patient’s body temperature to rise as opposed to decreasing body temperature. In this theory, CWI results in a peripheral vasoconstriction and

shivering which further increases body temperature.³ Larkin et al.⁸¹ were the first to state that CWI is restricted by conduction and further limiting the ability of the modality to cool a patient. Additional authors, including Strydom et al.⁸² proposed that peripheral vasoconstriction acts as a mechanism employed by the body to contain heat and that a potential rise in deep body temperature may also occur, while this is only the response in normothermic individuals. This theory was first refuted when it was found that a combination of covering the body in ice packs and hosing it down produced faster cooling rates than passive cooling alone.¹

Furthermore, CWI has been documented to produce 2-4 times more heat loss than air when compared at the same temperature gradient.⁸³⁻⁸⁶ In a group of participants that ran an 11.5-km race and were subsequently placed in a CWI tub in 1-3°C water, cooling rates of 0.2°C per minute were recorded.⁸⁷ Additional studies have been done examining the cooling rates observed with the use of CWI. Proulx et al.⁸⁸ evaluated the cooling rates of 2, 8, 14, and 20°C water temperatures in subjects as they progressed from 40°C to 37.5°C. Overall, the participants cooled at these various temperatures demonstrated cooling rates between 0.15°C and 0.19°C per minute.⁸⁸ The authors further observed the fastest cooling rates with 2°C water where cooling rates were on the order of 0.35°C per minute.⁸⁸ It has been further hypothesized by Marino et al.⁵⁰ that because ice-water immersion (IWI) and CWI allows for greater heat dissipation, blood is able to return from the periphery back to the core and subsequently decrease cardiovascular strain.

Clements et al.⁸⁹ investigated IWI and CWI as a means of cooling in runners experiencing exercise-induced hyperthermia. The objective of this study was to discover if CWI or IWI would serve as the most appropriate treatment for rapidly cooling hyperthermic runners. During this study, subjects participated in an exercise bout followed by cooling treatment. The

water temperature in the IWI and CWI trials was $5.15 \pm 0.20^{\circ}\text{C}$ and $14.03 \pm 0.28^{\circ}\text{C}$, respectively. The authors observed that IWI and CWI are both recommended for cooling the hyperthermic athlete due to similar cooling rates.⁸⁹ IWI had a cooling rate of $0.16 \pm 0.01^{\circ}\text{C}\cdot\text{min}^{-1}$, and CWI had a cooling rate of $0.16 \pm 0.01^{\circ}\text{C}\cdot\text{min}^{-1}$.⁸⁹ The authors acknowledged IWI and CWI as viable modes of cooling in the event an exertional heat illness becomes a life-threatening situation.

A multitude of studies have been performed demonstrating CWI possesses the greatest overall cooling rate of current modalities. CWI removes heat from the surface of the body in addition to cooling the circulating blood in the periphery.⁸⁸ A recent study has led to the development of evidence-based practice for the use of CWI in the treatment of EHS.

While CWI is relatively easy to set up and inexpensive, it can be difficult to have cold tubs located throughout athletic facilities where water sources may not be readily available. In addition, some sport settings, such as American football, may not allow for CWI because the equipment-laden aspect of the sport and the difficulty of removing equipment in a timely manner to make CWI's use beneficial. For this reason, it continues to be necessary to evaluate the efficacy of other cooling modalities capable of being easily transported across locations. Not only would an effective cooling modality prove helpful in terms of the ability to actively cool athletes on the field, but a mobile device could also be utilized while transporting a patient in the event of EHS.

Body Cooling

Of interest concerning the implementation of body cooling, is the timing of application of the cooling modality. Cooling the body frequently occurs during three time points: prior to

exercise, during exercise, and following exercise. The focus of this section refers to implementation of body cooling after exercise-induced hyperthermia.

A number of cooling modalities have been suggested as a means of reducing body temperature and potentially acting as an ergogenic aid to athletic performance. Throughout evaluating the current literature, some observations can be ascertained regarding possible performance benefits, the ability to effectively cool, and the potential to be utilized in equipment-laden activities. Among these modalities are CWI,^{87,89-91} hand cooling,^{92,93} ice towels,⁹⁰ clothing garments,^{90,94,95} ice slushes,⁹⁶⁻¹⁰⁴ and head cooling.^{90,105-108}

Cold-Water Immersion and Performance Benefits

Several performance benefits are known to result from utilizing CWI as a method of enhancing recovery. Performance, perception of recovery, and heart rate variability have all been shown to improve with or as a result of CWI. For example, aerobic exercise performance increased following CWI in water between 14-18°C.^{87,109} An important factor to consider when discussing performance benefits is the magnitude of improvement. When examining perception of recovery following CWI, Buchheit et al.⁹¹ investigated the effects of 5 minutes of CWI in a 14°C water bath on heart rate responses following supramaximal exercise carried out in the heat. Results showed that the perception of recovery was significantly improved with CWI compared to the passive recovery treatment. They made three additional observations following the conclusion of this study: exercise in the heat decreased all vagal-related heart rate variability following the conclusion of the first exercise bout, vagal-related heart rate variability was further decreased following the second exercise bout, and indicators of heart rate variability were significantly increased during the CWI condition. The authors postulated that the advantages of

these changes occur when parasympathetic reactivation following exercise can be preserved as a result of CWI.

When examining the effects of body cooling (CWI and IWI) between two exercise bouts performed in the heat on successive exercise performance Yeargin et al.⁸⁷ determined that CWI resulted in the fastest 2-mile performance time (725 seconds) compared to passive treatment (769 seconds). This observation represents a 6% improvement in race time that was not significant, however, it had a medium effect size 0.41. The authors also found CWI and IWI produced significantly lower rectal temperatures following both initial treatment and the subsequent performance test. Furthermore, heart rate was also found to remain significantly lower following CWI and IWI for trials for the first half of the 2-mile race. The decreases in rectal temperature allowed for an increased capacity for heat storage during subsequent exercise following cooling and elongated the time before the exercise limiting threshold of 39°C was reached.⁸⁷ It is possible that CWI and IWI resulted in improved time trials because the body was able to provide the working muscles with oxygen and glucose more efficiently due to the effects of cooling. Further, heart rate and rectal temperature were significantly impacted with cooling which plays a factor in overall athletic performance.⁸⁷ Yeargin et al.⁸⁷ was able to conclude that CWI and IWI can be used as an ergogenic aid between bouts of exercise performed in the heat. On the basis of the results of this study, it was possible to conclude that CWI has the potential to act as an ergogenic aid for athletic performance. As a result of this conclusion, the potential for CWI to be used in athletic settings is impactful. CWI could easily be implemented during half time of a soccer game, between periods in ice hockey, or even between halves of a basketball game.

Hand Cooling

Another cooling modality worth addressing is the use of a novel hand-cooling unit. The CoreControl unit formally known as the Rapid Thermal Exchange (RTX), is a device that cools the hand while supplying sub-atmospheric pressure to the hand. The CoreControl™ functions by combining negative pressure and the utilization of a heat sink to increase the removal of heat from the blood circulating in the hand and a cooling plate. The theory behind the negative pressure is such that it will act against the constricting subcutaneous venous plexuses in addition to increasing blood flow to the hand. Through cooling the circulating blood to the hand, it is thought that hyperthermia can be reduced.^{110,111} This device has been found to mitigate the rate of rise of rectal temperature significantly more than if no cooling modality was used in a second exercise bout.¹¹² Despite these findings, the CoreControl™ failed to yield significant cooling rates from the highest rectal temperature reached when compared to other cooling modalities.¹¹²

Grahn et al.⁹³ found mitigation in the rate of rise of esophageal temperature in subjects exercising in the heat in shorts and a t-shirt when the CoreControl™ unit was used. They also found an overall reduction in cardiovascular strain through the use of this device.⁹³ Amorim et al.⁹² discovered contrasting findings to Grahn et al. when they looked at the ability of the CoreControl™ to mitigate the rate of rise of core temperature in a population exercising in a hot, dry environment. The authors found the CoreControl™ hand-cooling device did not serve to reduce hyperthermia during exercise in a hot and dry environment while wearing summer uniforms and body armor. This research group believes this result is due the hand providing too small a surface area to provide the appropriate level of heat exchange required to dull the rate of rise of core temperature.⁹² These authors also addressed the possibility of skin blood flow reductions due to the cooling and subsequent vasoconstriction of the blood vessels.⁹² At this

point in time, more work regarding hand cooling should be done regarding its potential implications for mitigating rate of rise of rectal temperature, and uses for maintaining athletic performance.

Ice Towels

A key investigation led by DeMartini et al.⁹⁰ looked at various cooling modalities and their impact on both physiological marks and perceptual responses of mildly hyperthermic humans. Among the 10 body-cooling modalities used in this study were ice buckets. As a result of this being a field study, participants received the cooling treatment under a shaded area and had their hands to the midforearm, and feet to midcalf submerged in buckets filled with ice water (14°C). Participants exercised for approximately 45-60 minutes by playing recreational games outdoors in warm conditions (WBGT= 26.64 ± 4.71°C) prior to being cooled for 10 minutes. Two key findings came as a result of this investigation. After 10 minutes of cooling, T_{re} from minute zero of cooling to minute 10 of cooling decreased by $0.74 \pm 0.34^{\circ}\text{C}$, $p= 0.005$. This was significantly different than the decrease in T_{re} noted when participants cooled by resting in the sun ($0.42 \pm 0.15^{\circ}\text{C}$). An additional finding of this investigation was that it took CWI and ice buckets eight minutes to reduce body temperature by 1°F, whereas, it took 13 minutes for passive rest in the sun to achieve the same decline.

Clothing Garments and Performance Benefits

Among the range of modalities utilized for the purpose of externally cooling the body during exercise in the heat is the use of clothing garments such as jackets, vests, and shirts. These products may be indicated in the event an individual is not suffering from exertional heat illness, but rather in the event cooling may help maintain performance when exercise induced hyperthermia occurs.¹¹³ Trbovich et al.⁹⁵ utilized a cooling vest produced with renewable phase

change material composed of processed fats and oils. The vest has the ability to retain temperature of 15°C when chilled. Anecdotally, the subjects in the study stated that the vest was more comfortable on the skin as opposed to an ice vest in addition to maintaining the sensation of cold for the duration of each trial. Vests utilized in this study covered the shoulder, back, anterior chest, and abdomen. The authors found no significant effect on rectal temperature in any group.

Gao et al.⁹⁴ looked at the effect of cooling of phase change material vests on exercising subjects in the heat. While this study looked at the use of cooling garments in firefighters, this study is particularly applicable to equipment-laden sports, such as football. In this study, the authors looked at three conditions. The cooling conditions included vests with melting temperatures of 24°C and 28°C in addition a no cooling control condition. The authors found the 24°C cooling vest had the greatest effect on skin temperature compared to the 28°C cooling vest. Worth noting, is the observation that neither of the cooling vests had a significant cooling effect on body temperature rise mitigation.

DeMartini et al.⁹⁰ looked at two types of clothing garments intended to cool the body following exercise in the heat in a field study. The first of these garments was the Game Ready Active Cooling Vest™. This vest would be placed around the participants shoulders and zipped following an exercise bout in the heat and would subsequently be connected to the Game Ready unit. Cool water was then circulated through the vest and continued for 10 minutes. This particular modality did not yield a significant decrease in T_{re} . The Game Ready Active Cooling Vest™ did provide a greater overall reduction in T_{re} compared to passive rest in the sun ($p=0.893$) in addition to a cooling rate of 0.04°C/min.⁹⁰ The second cooling garment to be included in this study was the Nike Ice Vest™. This particular cooling device contains 22

pouches capable of holding ice packs. The innermost layer of the garment is composed of Nike Dri-Fit™ material that served as the layer between ice packs and the skin. Once again, this cooling garment failed to produce significant differences in T_{re} after 10 minutes of cooling. The decreases in T_{re} observed were; however, were greater than that observed with passive rest in the sun ($p=0.020$).⁹⁰ The cooling rate for this vest was $0.05^{\circ}\text{C}/\text{min}$.⁹⁰

While these studies serve as a critical foundation in the investigation of cooling garments, there is a wide range of studies that can continue to be done in the coming years. With that being said, another method of body cooling remains to be discussed. Several studies have been conducted evaluating the effectiveness of ingestible cooling modalities such as ice slurries and cold-water.

Ice Slushy and Performance Benefits

Studies carried out by Kay,⁹⁶ Siegel,⁹⁸ and Mundel¹⁰⁰ evaluated the effects of ice slushies on indicators of exercise performance. These authors have described decreases in body temperature, reduced cardiovascular strain, and overall performance benefits.^{96,98,100} A number of these studies have demonstrated a decreased body temperature with ingestion of cold beverages either before or during exercise in the heat, which may serve as the explanation for reductions in cardiovascular strain due to the redirection of blood flow from the skin the muscles.^{98,114-116} Furthermore, the performance benefits seen with cold drink ingestion could also be reflective of the input from thermoreceptors in the mouth and gastrointestinal tract eliciting greater sensations of reward, and an increased central drive.^{97,117}

Lee et al.¹⁰² had subjects complete three trials throughout the duration of their experiment. The trials consisted of ingesting a thermoneutral beverage, a cold drink, and a warm drink. The cold and warm drinks were 4°C and 28°C respectively. In this study, participants

exercised for a period prior to receiving an intervention. Participants would consume one of the experimental conditions while resting for 15 minutes prior to completing the same exercise and hydration protocol again. These authors found rectal temperatures to be lower in the cold-water condition compared to the warm water condition. On the basis of these findings, the authors postulated that consuming cold fluids after exercise bouts may decrease the amount of thermal strain imposed on the body in a second bout of exercise.¹⁰² It was also observed that the effects of cold-water ingestion were heightened throughout the exercise progression. Finally, these findings may further suggest cold drink ingestion as a mode for increasing the ability of an athlete to perform during endurance activities.¹⁰²

Burdon et al.¹¹⁸ conducted a study involving three experimental trials in which participants completed an exercise bout while ingesting one of the three experimental conditions. Subjects consumed a sports drink in the form of ice slushy, thermoneutral, or thermoneutral drink with an ice slushy mouthwash. Body temperature in each of the experimental conditions was found to have no significant changes between condition and time across trials. The authors were able to observe implications for benefits in performance with the ice slushy mouthwash trial. This observation coincides with the belief that the ingestion of a cold beverage has the ability to decrease one's perception of work, further enhancing their ability to perform.¹¹⁸

While it is true that ingestible cooling provides for a simple route of administration, its effectiveness at mitigating the rate of rise of body temperature has not been fully explored. The majority of existing work looks at pre-exercise data, and lacks in the area of body temperature attenuation during exercise. Beverages may be more easily integrated into the athletic training arena as a result of its mobile nature and ease of application; however, there is potential for yet another modality to be utilized during exercise in the heat.

Head and Neck Cooling

Head cooling represents an additional form of attempting to cool the body through the use of an external modality. While head cooling operates under the theory of cooling the skin and therefore decreasing the overall sensation of heat, it is also known that this action functions independently from decreasing body temperature.^{106,119,120} Even though the skin of the head and neck account for approximately 10% of the body's surface area, it has been previously demonstrated that cooling these areas as opposed to cooling a different 10% of the body's surface area is more effective at removing heat from the body.^{106,121,122}

Mundel et al.¹⁰⁸ looked closely at hormonal responses to face cooling during cycling exercise in warm conditions, in addition to obtaining perceptual information and core body temperature using rectal temperature. This protocol called for subjects to exercise to volitional fatigue using an incremental cycling exercise protocol. Two experimental conditions occurred in this study: face cooling and no-cooling. During the face cooling condition, participants assumed racing position while cycling and were sprayed with a cold-water mist. No cooling consisted of cycling in the same position with the absence of the cold-water mist. The authors state similar core temperature prior to the start of exercise and no differences occurred between the implementation of face cooling and no cooling trials. Interestingly, the authors found significantly lower heart rates with face cooling compared to no cooling (~5bpm) (See Figure 4).

¹⁰⁸ The authors hypothesized this occurred as a result of two possible mechanisms. The first of these mechanisms is referred to as the diving response.¹²³ During this response, the key stimulus

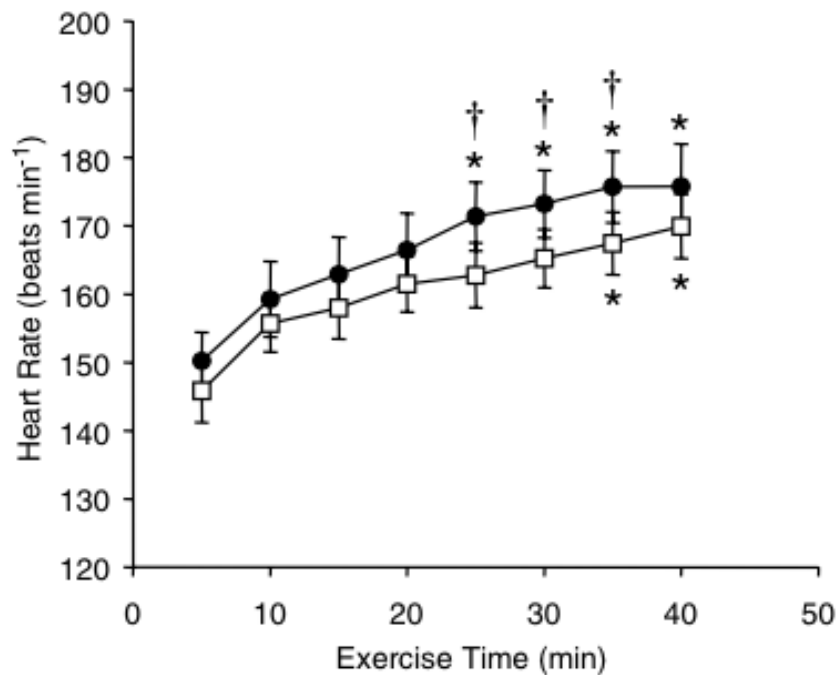


Figure 4-Mundel et al. The effects of face cooling during hyperthermic exercise in man: evidence for an integrated thermal, neuroendocrine and behavioral response. *Exp Physiol.* 92:(1):187-195. † represents significant differences between trials, *represents significant differences from 5 min value within a trial.

Brown et al.¹⁰⁵ evaluated the effects of head cooling on decreasing thermal strain in male pilots. Hyperthermia was induced in this study by passively sitting in a hot environment. T_{re} rise in the Brown et al.¹⁰⁵ study occurred as a result of participants passively heating for two hours while sitting in a 35°C environmental chamber while wearing shorts, t-shirt, socks, athletic shoes, aircrew coverall, liquid conditioned hood, and aircrew helmet. Body temperature was recorded via auditory canal and esophageal probes. Equipment worn in this study remained on as participants were cooled during the trial. Brown et al.¹⁰⁵ observed increases in both auditory and esophageal temperatures to approximately 38.0°C after two hours of passive heating. They further observed T_{re} rose to approximately 37.4°C when head cooling was implemented during the experimental trial. The authors noted that the rise in body temperature was attenuated by the introduction of head cooling. In the study by Brown et al.¹⁰⁵ cooling rate was not reported.

Nunnely et al.¹²⁴ performed a study looking at the effects of head and torso cooling on eight males during a simulated cockpit heat stress conditions. Head cooling consisted of a cap with patches having heat-sealed channels through which water flowed. The authors conducted the study in a controlled laboratory environment and recreated environmental conditions similar to that during flights in hot weather (dry bulb temperature was 35°C, wet bulb temperature was 26°C, 45% RH, and black globe temperature was 43°C). Participants donned cooling clothing, long cotton underwear, chemical defense garment, flight suit, anti-G suit, boots, impermeable gloves, oxygen mask, and flight helmet. Participants entered the environmental chamber and pedaled on an ergometer at 60 rpm for 10 min at a low load. Following this, participants sat in the environmental chamber and passively heated while cooling was applied. Participants exited the chamber after 100 minutes. Body temperature was monitored via rectal thermistor and slight increases in T_{re} were observed. The authors also noted that the use of a cooling cap had an influence on HR and T_{re} , although these findings were not significant. These findings were attributed to only being able to cool 3-4% of the body's surface area with the head-cooling cap. The authors stated they found cooling the head to be an extremely efficient method of body cooling and functioned to improve thermal stress. They reflected back to say that the degree of systemic influence was limited as a result of the small surface area utilized for cooling. In terms of heat removal in relation to surface area accessed via head cooling, the authors concluded that it was possible to remove as much as two to three times the amount of heat compared to the torso. Nunnely et al.¹²⁴ referenced three mechanisms by which head cooling functions in human populations: improved heat balance, brain cooling through countercurrent exchange in the neck, and decreased skin temperature which changes the afferent signals to the hypothalamus. Cooling rate was not reported.

Frim¹⁰⁷ conducted a laboratory study looking at the role of head cooling in preventing heat strain in pilots. This study was conducted in challenging environmental conditions where the wet bulb globe temperature was 35°C when the radiant component of heat to the head was taken out. Head cooling was performed through the use of a liquid cooled cap. Participants wore a cotton long-sleeved undershirt, cotton long pants, wool socks, summer-weight polyester/cotton flight suit, summer flying gloves with liners, and combat boots. Temperature was recorded rectally. Frim¹⁰⁷ described lack of consistency in time of exposure to the heat. Final T_{re} in the Frim¹⁰⁷ study ranged from 37.2-37.8°C. A cooling rate was not reported as a result of the timing of cooling used in this study protocol.

DeMartini et al.⁹⁰ performed a field study investigating the effects on body temperature of a head cooling unit called the Rehab Hood® (Chill Factor Performance Inc.). This unit functioned by covering it in water that served to activate microbeads placed in the lining of the apparatus and maintained in a refrigerator prior to use. This device covered the forehead and spanned to the posterior aspect of the neck in addition to covering the lateral head and ears. Cooling was applied to study participants for 10 minutes following an exercise bout in warm conditions. Significant reductions in T_{re} were not observed with this device, but did produce greater decreases in T_{re} compared to passive rest in the sun ($p=0.616$). Upon the conclusion of the 10-minute cooling period, this device was the only cooling modality in this study to generate a slower cooling rate than passive rest in the sun.

The American Football Uniform

While the American football uniform acts as a necessary component to participation in sport, it can further serve as an extrinsic factor to suffering an EHS. The protective equipment necessary for participation in American football creates a microclimate between the surface of

the skin and equipment.¹²⁵ As a result of this, the body's ability to lose heat to the environment via radiation, convection, and evaporation is decreased.⁷⁴ Up to 50% of the body's surface area is covered by the helmet and pads, and the addition of other clothing accounts for another 20% of the body's surface.¹²⁵ Additionally, American football athletes are generally thought to have larger body types and higher muscle masses.¹²⁶ Higher muscle mass is also associated with greater production of metabolic heat during exercise.¹²⁶ In combination with the intense physical activity of participating in American football and decreased ability to dissipate heat, athletes grow increasingly susceptible to entering a state of hyperthermia.^{126,127} Another drawback of wearing a large amount of athletic equipment is a decreased ability to lose heat to the environment through evaporation of sweat from the skin's surface. Evaporation represents the principle method the body uses to maintain core temperature.³² When the human body fails to lose heat via sweat from the surface of the skin, the body's temperature will continue to rise as exercise persists.³²

Among the vast array of factors identified to influence the body's ability to dissipate heat is the use of athletic equipment. The American football uniform in particular restricts the body's ability to lose heat via evaporation.¹²⁷ The body's ability to dissipate heat is impacted by several elements of the football uniform. These elements include the surface area of the body covered, the type of fabric composing the uniform, and additional protective equipment worn.¹²⁸ When an athlete wears a football uniform, a greater sweat rate may occur; however, a larger percentage of sweat typically drips off the body and fails to contribute to evaporative heat losses.^{129,130} The combination of environmental conditions, coupled with the microenvironment created through donning an American football uniform, football players become increasingly susceptible to hyperthermia.¹²⁷ (See Figure 5) In the event the body is unable to maintain a state of thermal

homeostasis, the athlete may suffer an EHS.¹²⁶ This extrinsic barrier to efficient heat dissipation poses a unique challenge to health care providers seeing to an EHS victim, maintain performance levels and cognitive function of athletes in the heat, and mitigate the rate of rise of body temperature.

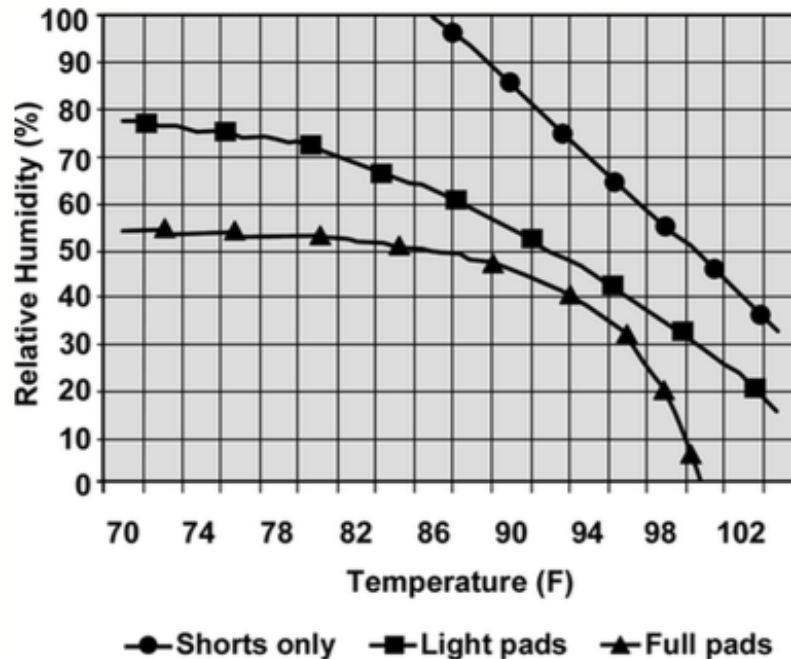


Figure 5—Binkley et al. National Athletic Trainers' Association Position Statement: Exertional Heat Illness. *Journal of Athletic Training*. 2002; 37(3):329-343

A study performed by Johnson et al.¹²⁶ concerning the perceptual responses of individuals exercising in the heat while wearing an American football uniform found that the increased physical strain associated with exercise in the heat is not associated with perceptual responses.¹²⁶ As a result of this finding, it can be established that a football athlete may not be aware of developing hyperthermia.¹²⁶ This may place them at an increased risk of EHS (See Table 2).

Condition	Exposure Time, min	Ratings at Participant Exhaustion/Protocol Completion			
		Rating of Perceived Exertion ^a	Thirst Perception ^b	Thermal Perception ^c	Overall Muscle Pain Perception ^d
Control	71.7 ± 13.4	14.5 ± 3.1	6.8 ± 1.8	5.9 ± 2.1	2.7 ± 3.1
Partial uniform	63.1 ± 15.6 ^e	17.3 ± 2.4 ^f	7.9 ± 1.2	7.1 ± 0.7	3.7 ± 2.7
Full uniform	56.2 ± 13.2 ^g	17.6 ± 1.4 ^h	7.5 ± 1.5	7.4 ± 0.4	3.6 ± 2.9

^a Scale range, 6 to 20.11.

^b Scale range, 0 to 9.17.

^c Scale range, 0 to 8.18.

^d Scale range, 0 to 10.19.

^e Different from control uniform group ($t_9 = 3.092$, $P = .013$).

^f Different from control uniform group ($t_8 = -3.849$, $P = .005$).

^g Different from control uniform group ($t_9 = 4.393$, $P = .002$).

^h Different from control uniform group ($t_9 = -3.108$, $P = .014$).

Table 2–Johnson et al. Perceptual responses while wearing an American football uniform. *Journal of Athletic Training*. 2010;45(2)107-116.

In supplement to the perceptual findings by Johnson et al.¹²⁶, Armstrong et al.¹²⁵ looked at uncompensable heat stress and hyperthermic exhaustion while wearing an American football uniform. The purpose of this particular study was to examine the effects of two types of American football uniforms and how the associated effects on exercise, thermal, cardiovascular, and hematologic responses. Participants in this study engaged in an exercise protocol while exercising in the heat and wearing a partial American football uniform (National Football League uniform (NFL) without a helmet and shoulder pads), or full American football uniform (full NFL uniform) with socks, sneakers, and shorts.

The authors found increased physiological strain occurs when donning the full NFL uniform compared to the partial uniform. Rectal temperature increased at a quicker rate compared to the partial uniform condition (See Table 3), in addition to displaying a decreased total exercise time¹²⁵ (See Figure 9). These findings suggest that a critical internal temperature and hypotension were associated with exhaustion during uncompensable heat stress conditions.

Experimental Condition	Rectal Temperature Increase, °C	Rate of Rectal Temperature Rise, °C/min	Total Exposure Time, min
Control clothing	1.81 ± 0.40	0.026 ± 0.008	71.7 ± 13.4
Partial uniform	2.36 ± 0.24 ^b	0.034 ± 0.006 ^b	63.1 ± 15.6
Full uniform	2.37 ± 0.45 ^b	0.042 ± 0.010 ^{b,c}	56.2 ± 13.2

^a Represents the period from the beginning of repetitive box lifting to the end of treadmill exercise, including 10-minute seated recovery after repetitive box lifting.

^b Indicates greater than control clothing condition (*P* range, <.001–.05; *d* range, 1.13–1.77).

^c Indicates greater than partial uniform condition (*P* = .04, *d* = 0.97).

Table 3-From Armstrong et al. *The American Football Uniform: Uncompensable Heat Stress and Thermal Exhaustion*. *Journal of Athletic Training*. 2010;45(2):117-127

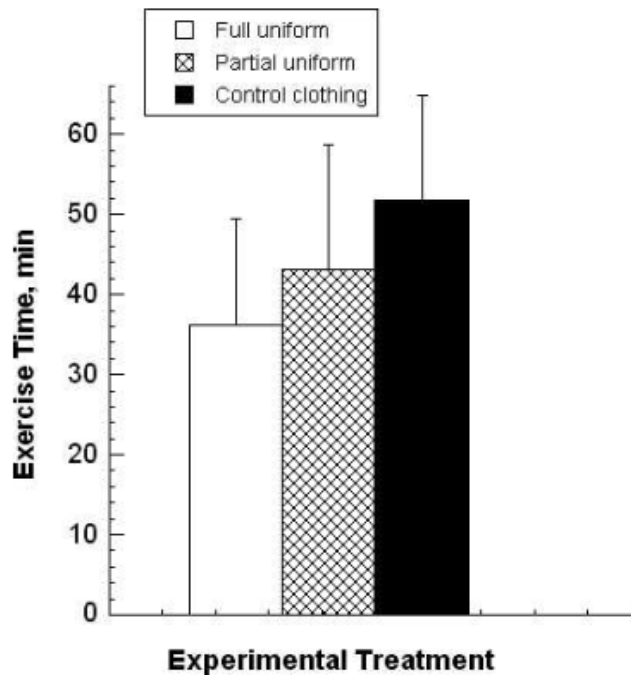


Figure 6-Armstrong et al. *The American Football Uniform: Uncompensable Heat Stress and Thermal Exhaustion*. *Journal of Athletic Training*. 2010;45(2):117-127

Equipment Laden Activities and the Need for Effective Cooling

In addition to the potential medical problems associated with heat stress, decreases in exercise performance and increases in the rating of perceived exertion (RPE) occur as a result of

the physiological changes associated with exercising in the heat.¹³¹⁻¹³⁴ Increases in RPE have also been documented with exercising in a football uniform.^{128-130,135-137} Johnson et al.¹²⁶ reported an increased RPE and decreased exercise time with the addition of a football uniform in comparison to the control condition in which participants exercised in shorts, socks, and sneakers.¹²⁶

Using a cooling modality as a means to mitigate the rate of rise of body temperature in an exercising individual presents a set of unique challenges specific to sport, laborers, and warfighters. While cooling modalities can help improve athletic performance and decrease the risk of heat illness, utilization of cooling modalities during athletic events can be particularly challenging. One of the most challenging components of the task of body cooling is the equipment worn. Professions such as firefighting and being a professional soldier face many of the same barriers to cooling as athletes participating in equipment laden sports. The efficacy of different cooling modalities should continue to be researched and developed within the confines of the rules of sport, physical activity, and other equipment-laden activities. In the event effective cooling can be implemented in equipment-laden activities without interrupting the nature of the activity, individuals would be able to experience performance benefits in addition to actively reducing their risk of suffering an exertional heat illness such as EHS.

Chapter II.

The Influence of Head Cooling Combined with Various Cooling Modalities on Cooling Rate After Exercise in the Heat

Introduction

It has been established that exertional heat illnesses (EHI) are an inherent risk of athletic participating with exercise-induced hyperthermia. Exertional heat stroke (EHS) represents the most life threatening of injuries sustained during physical activity, and a number of factors have been identified to increase one's risk of suffering an exertional heat illness.^{1,15,138} These factors include hot environmental conditions, lack of heat acclimatization, and hydration status.^{15,138} Another factor known to increase the risk of EHS is the use of protective equipment. This can be in the form of the American football uniform, warfighter gear, or protective equipment worn by laborers.

Individuals participating in equipment-laden activities are known to be more prone to suffering from an EHI especially when hot environmental conditions are present.¹²⁵ A microenvironment is created between the surface of the skin and the additional clothing, further limiting evaporation of sweat from the body, convection, or conduction and increased temperature and humidity within the microenvironment.¹²⁵ As a result of these barriers to cooling, a number of methods of body cooling have been investigated.^{87,89-100,102,103,105-108,115,120,139,140}

Different types of body cooling modalities have been utilized in an effort to decrease core body temperature before, during, and after physical activity.⁹⁰ These body-cooling modalities include cold-water immersion,^{87,89-91} hand cooling,^{92,93} ice towels,⁹⁰ clothing garments,^{90,94,95} ice slushes,^{96-98,100,102,104,115,141} and head and neck cooling.^{90,105-108} Some effective methods of mitigating the rise in core temperature are impractical due to uniform and equipment restrictions. As a result, it is imperative to utilize a method of body cooling that is effective at reducing core temperature and one that can avoid the hindrance of protective equipment. The potential for a

head-cooling device is such that they offer a convenient option for the equipment-laden individual during recovery periods.

The Temperature Management System® (TMS) is a head cooling device in which a cap is placed on the head and utilizes both air and liquid pumps that function to pressurize and circulate chilled coolant to the outer, middle, and inner layers of the headliner. Few studies have evaluated the ability of a head-cooling device to reduce rectal temperature. Hyashi et al.¹³⁹ found that rectal temperature during exercise was attenuated after approximately 60 minutes of cycling in a hot environment when head cooling was implemented. In contrast, Mündel et al.¹⁰⁸ and Ansley et al.¹⁴⁰ both discovered that rectal temperature post-exercise was unchanged when cooling was implemented to the head in the form of a cold-water mist. At this juncture, more data should be collected to investigate the effect head cooling has on mitigating the rate of rise on body temperature.

Based on the current literature and the need to further substantiate alternative methods of body cooling, this study was performed with the primary objective to determine the efficacy of various combinations of a head cooling device, forearm ice towels, and cold-water immersion on lowering internal body temperature. It was hypothesized that the addition of head cooling to commonly used body cooling modalities would supplement previously documented cooling rates.

Methods

Experimental Protocol

Participants attended seven sessions, including one familiarization session and six testing sessions. Each of the sessions was separated by a minimum of one day time for participant recovery. The testing sessions were conducted using a randomized, counterbalanced, cross over

design in which participants acted as their own control. Participants completed an exercise bout followed by a series of two cognitive tests and three exercise performance tests. Participants then completed a cooling session followed by a second set of cognitive tests and three exercise performance tests. Each testing session utilized one of six different cooling treatments: 1) cold-water immersion (CWI), 2) head cooling (HC), 3) forearm ice towels (IT), 4) cold-water immersion and head cooling (CWI + HC), 5) forearm ice towels and head cooling (IT + HC), 6) passive rest. The study took place in the Human Performance Laboratory at the University of Connecticut. The study was carried out in the thermal physiology laboratory, complete with an environmental chamber (Model 200, Minus Eleven, Inc., Malden, MA). Variables such as rectal temperature (T_{re}), HR, tympanic temperature (T_{tym}), as well as perceptual scales (Rating of Perceived Exertion (RPE), Thermal, Thirst, Fatigue, Environmental Symptoms Questionnaire (ESQ)) were recorded. Performance test variables after (POST) exercise included the Foot Speed Drill, React Drill, and 30-second sprint test. Performance test variables POST cooling (POST-C) included the Foot Speed Drill (FS), React Drill (REACT); 30-second sprint test (SPT) on a non-motorized treadmill, and aerobic run test (RT). The experimental protocol is visually depicted in Figure 10.

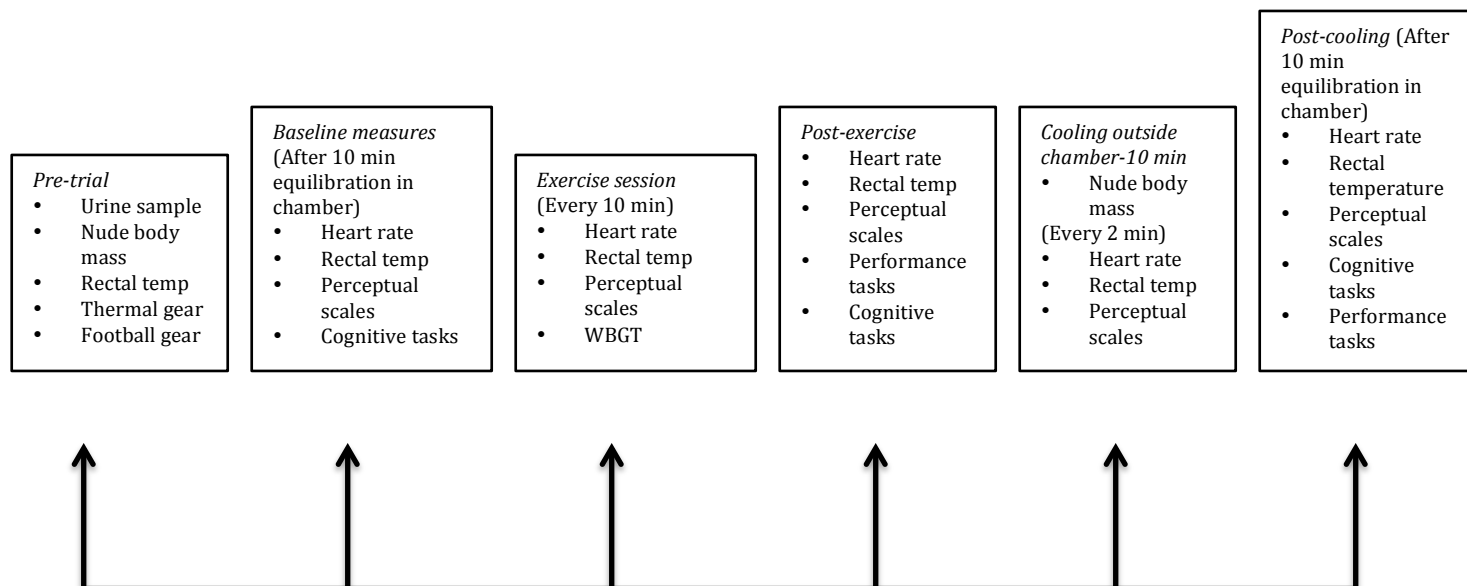


Figure 10- Flow chart for all six experimental sessions. The only changes occurring were the different cooling treatments: CWI, HC, IT, CWI+HC, HC+IT, passive rest.

Participants

The Institutional Review Board at the University of Connecticut approved the experimental protocol for this study. Prior to the participant's participation in the study, verbal and written informed consent was obtained from each volunteer. Fourteen college-aged, recreationally active individuals (7 males, 7 females) participated in this study.

In order to be deemed recreationally active, participants were required to engage in at least 30 minutes of physical activity 4-5 times per week. Prior to participation, participants had to meet the following criteria: body fat (males, <24%; females, <31%) and $\text{VO}_{2\text{max}}$ (males, >50 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; females, >40 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$). Percentage of body fat was determined using a DEXA scanner (GE Lunar Prodigy Dual X-Ray Absorptiometry, General Electric Fairfield, CT) and software (GE Encore Healthcare 2006, Madison, Wisconsin) (Version 10.10.038). Dual X-Ray Absorptiometry (DEXA) measurements were obtained with the participant in the supine position

by a radiology technician according to the manufacturer's guidelines prior to the onset of the experimental protocol. Female participants completed a menstrual history questionnaire and pregnancy test prior to testing in the experimental protocol. In order to control for changes in body temperature occurring throughout the female menstrual cycle, females completed testing during days 1-17 of their cycle.^{142,143} In addition, medical screening information was obtained via medical history questionnaire to ensure subjects met the following criteria: 1) no chronic health problems, 2) no fever or current illness at the time of testing, 3) no history of cardiovascular, respiratory, or metabolic disease, 4) no current musculoskeletal injury that limits their physical activity, 5) not currently pregnant as determined by a pregnancy test, 6) no history of exertional heat illness within the past 3 years, and 7) no irregular menstrual cycle for female subjects.

Familiarization Session

Participants began the study with a familiarization session a minimum of one day prior to the start of exercise sessions. This session included obtaining measures of participant height, weight, and resting heart rate. A pregnancy test was done for females. DEXA scans were completed as a means to assess body fat percentage and a $\text{VO}_{2\text{max}}$ test was completed to measure maximal oxygen consumption. In order to familiarize participants with the various elements of the study, each participant was guided through the procedures for the cognitive and performance tasks. Three-day averages of urine measures and weight were obtained to serve as baseline measures.

Participants completed the Profile of Mood States (POMS) and Environmental Symptoms Questionnaire (ESQ). Each participant was introduced to the performance tasks and they performed each task until they were able to correctly perform the task. This was done to

eliminate a learning effect while completing the tasks during experimental sessions. In order to minimize bias due to a learning effect and ensure participant safety, participants were also instructed on the correct procedures for each cognitive and exercise performance task and provided time to practice each task. Participants were familiarized with the various perceptual scales used throughout the protocol as indicated in previous studies.¹⁴⁴⁻¹⁵⁰

Experimental Sessions

Participants were asked to wear similar exercise clothing for each exercise session. Participants were properly fitted with a football helmet (Riddell, Speed), shoulder pads (Riddell, Power CPX30), football pants (Nike, Team Apparel [with internal tailbone, thigh (Bike), and knee (Schutt) pads]), and football jersey (Nike, Team Apparel) over the top over the shoulder pads. Participants were also sized for a long sleeve thermal shirt (Under Armor/Men's UA ColdGear® Infrared Devo Crew) and thermal leggings (Under Armor/Men's ColdGear® Infrared Tactical Fitted Leggings) that were to be worn during each session. Throughout the testing protocol, participants were monitored via a rectal thermometer (Measurement Specialties 3600), and heart rate strap (The Timex Group, Inc. Middlebury, CT). Upon arrival at the lab, participants provided a urine sample and hydration status was determined by urine color (U_{COL}) and urine specific gravity (U_{SG}) using a handheld refractometer (Atago 300 CL, Atago, Japan). Participants then provided a nude body mass and inserted a rectal thermistor (DataTherm, Wixom, MI) 10cm beyond the anal sphincter.

Furthermore, to ensure female participants were not pregnant throughout the duration of the study, they provided a urine sample in a clean urine cup prior to each exercise sessions. This urine sample was analyzed using a handheld pregnancy test (Fisher HealthCare™/Sure Vue™ Serum/Urine hCG test kit) by the researchers to determine pregnancy status.

Exercise Trials

Upon arrival to the laboratory for testing sessions, participants were given a clean urine cup to provide a urine sample to assess hydration status using U_{SG} and U_{COL} . If the participant was determined to be hypohydrated ($U_{SG} > 1.020$), an additional bolus of 500mL of water was given to the participant to drink prior to entering the environmental chamber. For female subjects, a pregnancy test was then performed before continuing on with the rest of the testing session. Participants had their nude body mass recorded and then participants inserted a rectal thermometer 10cm beyond the anal sphincter as instructed during the familiarization session.

Participants then donned a heart rate telemetry strap and completed the POMS, ESQ and cognitive performance tests as indicated in the familiarization session. Upon completion of these baseline tests, participants then donned a long sleeve thermal shirt, long thermal pants, football pants with thigh and knee pads, football jersey and shoulder pads, a football helmet and sneakers.

Once participants were fully dressed in all respective gear, they entered the environmental chamber and sat for 10 minutes to become equilibrated to the environmental conditions.

After the 10-minute equilibration period, perceptual measures were recorded at this time. The perceptual measures obtained were Rating of Perceived Exertion (RPE), thermal sensation, thirst sensation and fatigue. Baseline measures of heart rate, rectal temperature, tympanic temperature, and perceptual scales were obtained. The perceptual scales included RPE, thermal sensation, thirst sensation and fatigue. Participants then began walking on a motorized treadmill between 3.0 and 4.5mph at a 5% incline until one of the following occurred: 1) Rectal temperature $> 39.75^{\circ}\text{C}$, 2) Participant requested to stop, 3) Heart rate $>$ age predicted maximum ($220 - \text{subject age}$) for 5 minutes, 4) Participant displayed and altered or uneven gait, 5) or 80

minutes of exercise had elapsed. Participants determined their own walking speed with a pace that was considered both fast and sustainable for the maximum 80 minutes of exercise. Heart rate, temperature, and perceptual scales were measured every 10 minutes. During the exercise bout, participants were provided 200mL of water at minutes 20 and 40 of exercise. All participants underwent similar treadmill exercise times (55.0 ± 12.7 minutes).

At the completion of the exercise bout, subjects removed all football equipment and thermal gear and changed into shorts and a t-shirt prior to complete the ESQ, POMS, and cognitive and performance tests previously described. After completion of the cognitive and performance tests, a researcher then escorted the participant to a nearby locker room where they towed dry and provided a nude body mass. Participants redressed in shorts (and a sports bra or sports bra and t-shirt for females) and the cooling portion of the testing session began.

Participants were randomly assigned cooling trials, and the order of cooling condition trials was determined prior to the start of testing. Additionally, the order of cooling trials was counterbalanced between participants to ensure an order effect related to cooling was not present. Each participant completed six cooling trials as a part of this study. Cooling was applied for 10 minutes in the seated position outside of the environmental chamber ($22.4 \pm 1.6^{\circ}\text{C}$, $32.1 \pm 12.3\%$ RH). During cooling, rectal temperature, tympanic temperature, heart rate, and perceptual scales were measured every 2 minutes. Cooling was stopped to ensure participant safety and account for rectal temperature after drop if the participant's rectal temperature reached 38.0°C or 10 minutes of cooling elapsed. CWI and IT water temperatures were similar across cooling trials, 14.47°C and 4.7°C , respectively.

Upon completion of the cooling session, participants returned to the environmental chamber and sat to equilibrate for 10 minutes. Participants then repeated the POMS, ESQ,

cognitive and exercise performance tests. At this time, the subject completed the additional exercise performance test evaluating aerobic performance described previously.

Once the participant completed all cognitive and exercise performance tests they exited the environmental chamber. Participants provided a final nude body mass and urine sample, in which USG and U_{COL} were assessed.

Exercise sessions were performed a minimum of 24 hours apart. The study was performed in the late winter and early spring and participants were not acclimatized to exercise in the heat.

Cooling Modalities

Cold-water Immersion

The participant sat quietly in a 150-gallon stock tank (Rubbermaid, 150 Gallon Structural Foam Stock Tank) and was immersed in cold-water to the level of their clavicles. Water was disrupted every two minutes when the participant rose up out of the water for the purpose of obtaining measures of heart rate, but the water was not circulated. Participants then dried off and put dry clothes on prior to returning to the environmental chamber.

Head Cooling Device

The participant wore the Temperature Management System® head cooling device. This device consists of a cap that is placed on the head and utilizes both air and liquid pumps that function to pressurize and circulate chilled coolant to the outer, middle, and inner layers of the headliner. In conjunction with the unit's elastic properties, the surface of the cooling unit possesses the potential ability to cling closely to the patient's skin further encouraging heat transfer between the unit and the patient's skin.

The participant's hair was sprayed with water and they sat quietly in an empty 150-gallon stock tank wearing the Temperature Management System® head cooling device (Welkins, LLC/Downers Grove, IL). The device utilized air and liquid pumps that functioned to pressurize and circulate chilled cooling to the outer, middle and inner layers of the headliner.

Forearm Ice Towels

The participant sat quietly in an empty 150-gallon stock tank with each forearm propped over a plastic bucket (Unger, Pro Bucket, Bridgeport, CT) containing ice water. Towels were soaked in the ice water and then placed over each of the participant's forearms. The towels were rotated and re-saturated with ice water every two minutes.

Cold-water Immersion and Head Cooling Device

The participant sat quietly in an empty 150-gallon stock tank while wearing the head-cooling device.

Forearm Ice Towels and Head Cooling Device

The participant sat quietly in a 150-gallon empty stock tank each forearm propped over a plastic bucket containing ice water. Towels were soaked in the ice water and then placed over each of the participant's forearms. The towels were rotated and re-saturated with ice water every two minutes. The subject also wore the head-cooling device on their head.

Passive Rest

The subject sat quietly in a 150-gallon empty stock tank.

Statistical Analysis

Data were analyzed using SPSS version 21.0 (IBM Corporation, Champaign, IL, USA) with an a-priori alpha level of 0.05. A one-way between-subjects ANOVA was used to measure differences between the cooling rates of each of the six cooling treatments for HR, starting and

ending exercise temperature, environmental conditions, and total exercise time. A two-way mixed model ANOVA measured differences in cooling treatment by time. When applicable, Tukey post-hoc analyses determined differences between individual cooling treatments.

Results

Participant Demographics

Mean (\pm SD) physical characteristics of the participants were: age 25.3 ± 3.6 y, height 171.4 ± 9.2 cm, weight 70.8 ± 8.3 kg, body fat $21.2.4 \pm 7.6\%$, VO_{2max} 49.5 ± 6.6 ml·kg⁻¹·min⁻¹, weekly exercise 270 ± 66 min·week⁻¹, and resting heart rate 63 ± 9 beats per minute (See Table 1).

Table 1-Participant demographic information collected during familiarization session. * Indicates significant differences between men and women.

	Male (n=7)	Female (n=7)	Combined (n=7)	
	Mean \pm SD	Mean \pm SD	Mean \pm SD	P value
Age (y)	24.9 ± 3.9	25.8 ± 3.6	25.3 ± 3.6	0.633
Height (cm)	177.9 ± 6.1	164.9 ± 6.8	171.4 ± 9.2	0.003*
Body Mass (kg)	77.0 ± 3.3	64.7 ± 7.0	70.8 ± 8.3	0.001*
Body Fat (%)	15.4 ± 6.8	27.0 ± 1.5	21.2 ± 7.6	0.004*
VO_{2max} (ml·kg ⁻¹ ·min ⁻¹)	54.3 ± 5.2	44.8 ± 3.9	49.5 ± 6.6	0.002*
Weekly Exercise (min·week ⁻¹)	236 ± 67	298 ± 54	270 ± 66	0.092
Resting Heart Rate (bpm)	60 ± 9	66 ± 9	63 ± 9	0.257

*Significantly different men vs. women ($p < 0.05$).

Environmental Conditions

Air temperature and relative humidity were consistent across cooling conditions ($p > 0.05$) during exercise and cooling trials as presented in Table 2.

Table 2-Environmental conditions during exercise and cooling trials.

	Exercise		Cooling	
	Mean	SD	Mean	SD
Temperature (°C)	38.5	1.5	22.4	1.6
Relative Humidity (%)	37.5	7.6	32.1	12.3

Water Temperature

The water temperature for CWI ($14.5 \pm 2.2^{\circ}\text{C}$) and CWI + HC ($14.6 \pm 2.1^{\circ}\text{C}$) trials were similar ($p=0.95$) as well as the water for IT ($5.9 \pm 3.5^{\circ}\text{C}$) and HC + IT ($4.0 \pm 3.2^{\circ}\text{C}$, $p=0.32$).

Rectal Temperature

At the beginning of exercise trials, all participants began exercise at a similar T_{re} ($p=0.955$). Additionally, participants had similar end of exercise T_{re} ($p>0.832$). T_{re} during exercise bouts at the start of exercise, 30 minutes into the exercise bout, and immediately post exercise for each cooling condition is depicted in Table 3.

Table 3-Average rectal temperature ($^{\circ}\text{C}$) during exercise bouts at minute 0, minute 30, and immediately post exercise (IPE) IPE for all conditions: cold-water immersion (CWI), head cooling (HC), ice towels (IT), CWI+HC, HC+IT, passive. * Indicates significant differences between groups for rectal temperature during exercise bouts.

Rectal temperature during exercise bouts ($^{\circ}\text{C}$)						
	Minute 0		Minute 30		IPE	
	Mean	SD	Mean	SD	Mean	SD
CWI	37.28	0.26	38.28	0.35	39.17	0.45
HC	37.15	0.30	38.10	0.35	39.14	0.49
IT	37.17	0.24	38.14	0.32	39.13	0.50
CWI + HC	37.19	0.23	38.26	0.39	39.20	0.45
HC + IT	37.20	0.30	38.27	0.42	39.23	0.49
Passive	37.16	0.32	38.14	0.29	39.14	0.47

At the onset of cooling, all participants had similar T_{re} ($39.35 \pm 0.48^{\circ}\text{C}$, $p>0.05$). T_{re} during each cooling condition for each 2-minute increment is depicted in Table 4. As a result of removing participants from cooling when their T_{re} reached 38.0°C , all of the participants did not cool for 10 minutes. The n-size of participants cooling for each modality over each 2-minute time point during cooling is depicted in Table 5. Average T_{re} during cooling in response to each cooling modality is depicted in Table 4 and Figure 11. The T_{re} for each body cooling modality is

representative of the average T_{re} of male and female participants. Although no statistical differences were observed, CWI + HC reflected the lowest T_{re} during the 10-minute cooling period compared to all other body cooling modalities as depicted in Table 4.

Table 4-Average rectal temperature (°C) during cooling at minute 0, 2, 4, 6, 8, and 10 for all conditions: cold-water immersion (CWI), head cooling (HC), ice towels (IT), CWI+HC, HC+IT, passive. *Indicates significant differences between rectal temperatures during cooling.

Rectal temperature during cooling (°C)												
	Minute 0		Minute 2		Minute 4		Minute 6		Minute 8		Minute 10	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
CWI	39.30	0.53	39.02	0.49	38.74	0.46	38.67	0.37	38.51	0.31	38.40	0.28
HC	39.22	0.59	39.05	0.50	38.86	0.47	38.69	0.43	38.55	0.39	38.50	0.33
IT	39.29	0.57	39.01	0.53	38.82	0.47	38.61	0.46	38.50	0.40	38.40	0.39
CWI + HC	39.20	0.41	38.86	0.35	38.60	0.31	38.46	0.27	38.31	0.29	38.26	0.22
HC + IT	39.31	0.72	39.05	0.50	38.78	0.54	38.64	0.49	38.56	0.44	38.38	0.40
Passive	39.26	0.45	39.13	0.45	38.97	0.44	38.83	0.46	38.77	0.40	38.64	0.37

Table 5-n-size of rectal temperature taken during minute 0, 2, 4, 6, 8, and 10 during cooling for all conditions: cold-water immersion (CWI), head cooling (HC), ice towels (IT), CWI+HC, HC+IT, passive.

n-size of rectal temperature during cooling						
	Minute 0	Minute 2	Minute 4	Minute 6	Minute 8	Minute 10
CWI	14	14	14	12	12	11
HC	14	13	13	13	13	11
IT	14	14	14	14	13	11
CWI + HC	13	13	13	11	10	8
HC + IT	13	12	13	12	10	10
Passive	14	14	14	14	13	13

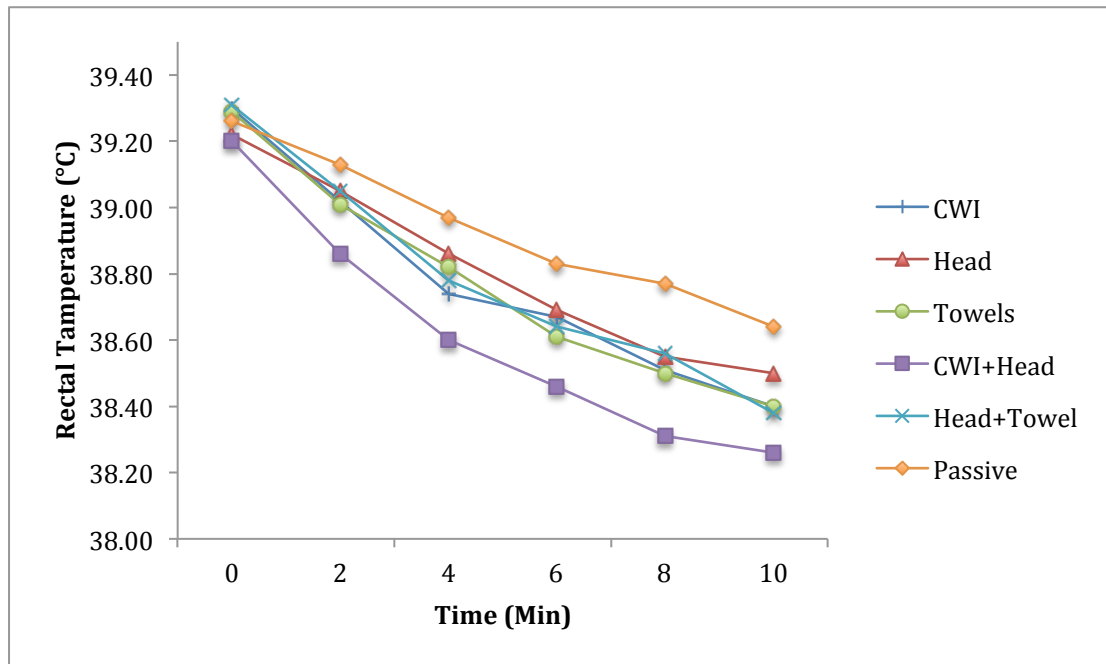


Figure 11-Average rectal temperature (°C) during cooling for all conditions: cold-water immersion (CWI), head cooling (HC), ice towels (IT), CWI+HC, HC+IT, passive.

Absolute change in T_{re} in response to each cooling modality is represented by change in T_{re} from the onset of cooling compared to each 2-minute increment during cooling. Change in T_{re} during cooling is depicted in Figure 12. Once again, participants began cooling at similar T_{re} and although statistical differences were not observed ($p>0.05$), CWI + HC produced the greatest average change in T_{re} during the 10-minute cooling treatment.

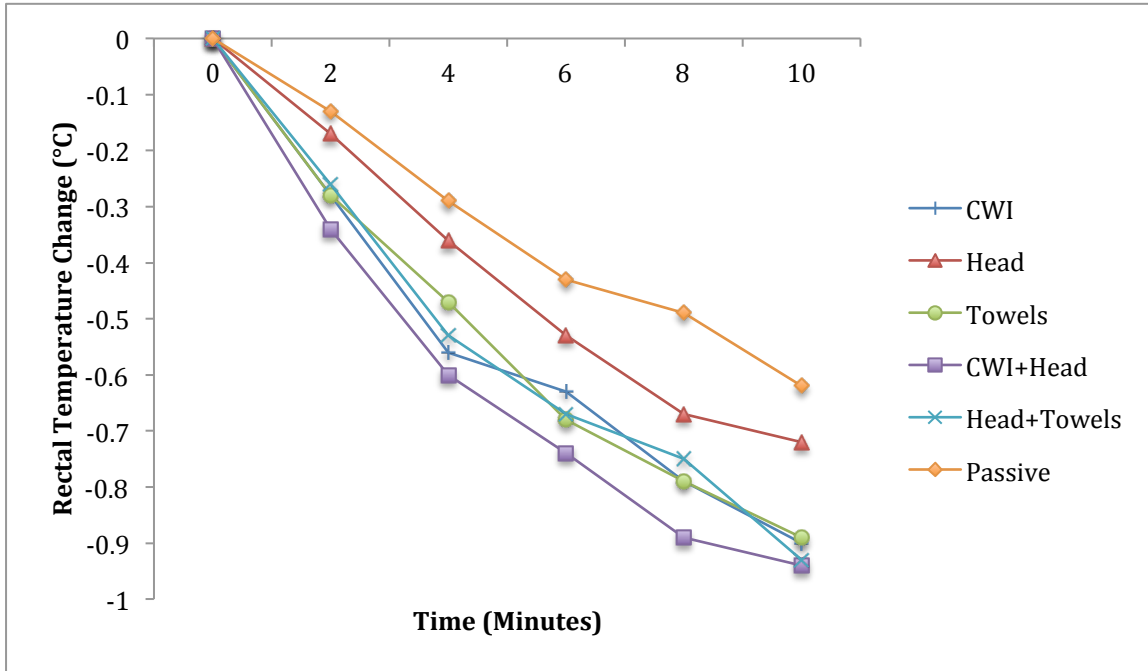


Figure 12-Average change in rectal temperature (°C) during cooling for all conditions: cold-water immersion (CWI), head cooling (HC), ice towels (IT), CWI+HC, HC+IT, passive.

Cooling Rate

A comparison of the addition of HC to other cooling modalities was conducted to examine differences compared to cooling modalities independently. CWI + HC produced a cooling rate of $0.13 \pm 0.07^{\circ}\text{C} \cdot \text{min}^{-1}$ compared to CWI alone ($0.11 \pm 0.06^{\circ}\text{C} \cdot \text{min}^{-1}$, $p=0.43$). The passive cooling rate ($0.07 \pm 0.02^{\circ}\text{C} \cdot \text{min}^{-1}$) was lower than all other cooling conditions ($p<0.014$) except for HC ($0.09 \pm 0.04^{\circ}\text{C} \cdot \text{min}^{-1}$, $p=0.073$). The cooling rate for CWI + HC ($0.13 \pm 0.07^{\circ}\text{C} \cdot \text{min}^{-1}$) compared to HC ($0.09 \pm 0.04^{\circ}\text{C} \cdot \text{min}^{-1}$) trended towards significance ($p=0.052$).

The addition of HC to IT did not result in an enhanced cooling rate ($0.13 \pm 0.07^{\circ}\text{C} \cdot \text{min}^{-1}$) compared to IT ($0.11 \pm 0.05^{\circ}\text{C} \cdot \text{min}^{-1}$, $p=0.215$). Cooling rates for males, females, and combined values for each cooling modality are depicted in Table 6. Figure 13 depicts the cooling rate of passive rest, HC, IT + HC, and CWI + HC.

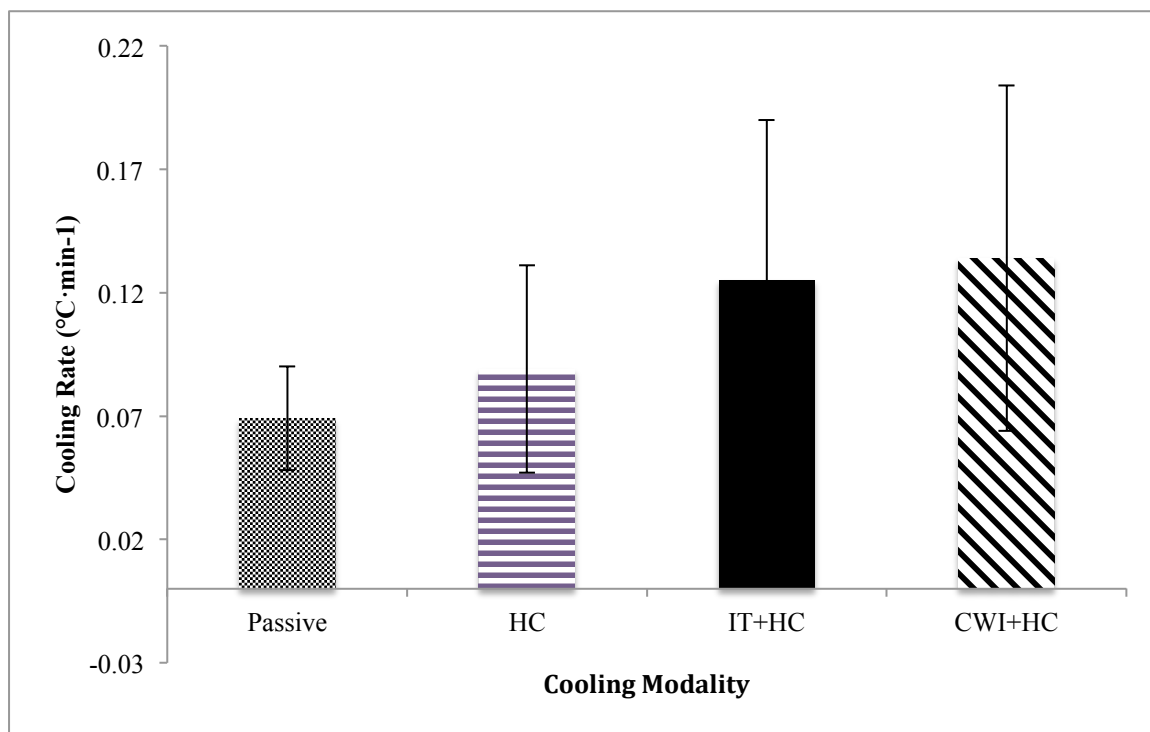


Figure 13-Comparison of average cooling rate ($^{\circ}\text{C}\cdot\text{min}^{-1}$) for passive, head cooling (HC), ice towels (IT)+HC, and CWI+HC.

Table 6-Comparison of cooling rates ($^{\circ}\text{C}\cdot\text{min}^{-1}$) between males, females, and combined for all conditions: cold-water immersion (CWI), head cooling (HC), ice towels (IT), CWI+HC, HC+IT, passive. *Indicates significant differences from all other cooling modalities ($p>0.05$).

Comparison of cooling rate across conditions using ($^{\circ}\text{C}\cdot\text{min}^{-1}$)						
	Male		Female		Combined	
	Mean	SD	Mean	SD	Mean	SD
CWI	0.106	0.059	0.119	0.061	0.111	0.058
HC	0.100	0.046	0.073	0.035	0.089*	0.042
IT	0.087	0.028	0.137	0.071	0.108	0.054
CWI + HC	0.136	0.081	0.132	0.061	0.134	0.070
HC + IT	0.113	0.050	0.141	0.085	0.125	0.065
Passive	0.063	0.021	0.077	0.021	0.069*	0.021

Cooling rates for men, women, and combined for each cooling condition are graphically represented in Figure 14. While statistical differences were not found between genders ($p=0.56$), passive rest demonstrated the slowest combined cooling rate compared to all other body cooling modalities in this study with the exception of head cooling ($p=0.169$). CWI + HC demonstrated the greatest overall cooling rate; however, this finding was not significant.

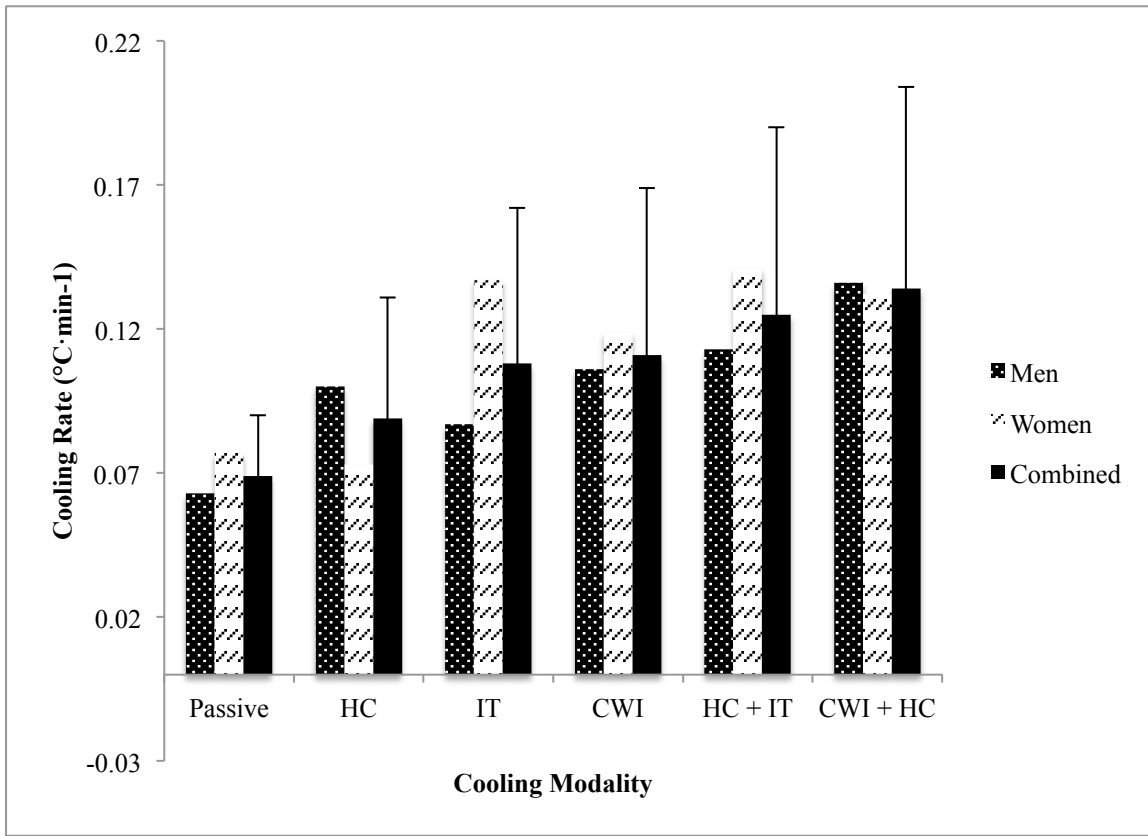


Figure 14- Comparison of cooling rates ($^{\circ}\text{C}\cdot\text{min}^{-1}$) between males, females, and combined for all conditions: cold-water immersion (CWI), head cooling (HC), ice towels (IT), CWI+HC, HC+IT, passive.

T_{re} immediately following the cessation of cooling for each cooling condition was obtained and is depicted in Table 7. A one-way ANOVA ($p=0.03$) revealed differences between CWI and CWI+HC ($p=0.04$) and passive cooling vs. CWI+HC ($p=0.02$).

Table 7- Average resting rectal temperature ($^{\circ}\text{C}$) immediately post cooling for all conditions: cold-water immersion (CWI), head cooling (HC), ice towels (IT), CWI+HC, HC+IT, passive. *Indicates significant differences.

Resting rectal temperature immediately post cooling ($^{\circ}\text{C}$)		
	Mean	SD
CWI*	38.37	0.29
HC	38.39	0.36
IT	38.33	0.41
CWI + HC*	38.11	0.30
HC + IT	38.28	0.44
Passive*	38.57	0.40

Approximately 40 minutes following the start of cooling, total drop in T_{re} for CWI and CWI + HC conditions were similar ($3.60 \pm 1.02^{\circ}\text{C}$, $3.74 \pm 0.95^{\circ}\text{C}$, respectively $p>0.05$) and resulted in lower T_{re} than all other cooling conditions ($p<0.05$). This finding indicated that CWI continues to cool the body, termed after drop, after individuals are removed from the water. Table 8 depicts resting T_{re} 40 minutes after the onset of cooling. CWI and CWI+HC were not different from one another.

Table 8-Resting rectal temperature ($^{\circ}\text{C}$) for all conditions 40 minutes after the onset of cooling: cold-water immersion (CWI)*, head cooling (HC), ice towels (IT), CWI+HC*, HC+IT, passive. *Indicates significant difference from all other cooling conditions ($p<0.05$).

Resting rectal temperature 40 minutes after the onset of cooling ($^{\circ}\text{C}$)		
	Mean	SD
CWI	37.38*	0.11
HC	37.90	0.08
IT	37.75	0.04
CWI + HC	37.19*	0.12
HC + IT	37.79	0.10
Passive	37.87	0.09

Figure 15 depicts the cooling rates of CWI and passive rest across each individual participant. There was high variability among subjects in response to CWI as is visually represented by Figure 15, Participants appeared to cool faster with CWI than with passive rest.

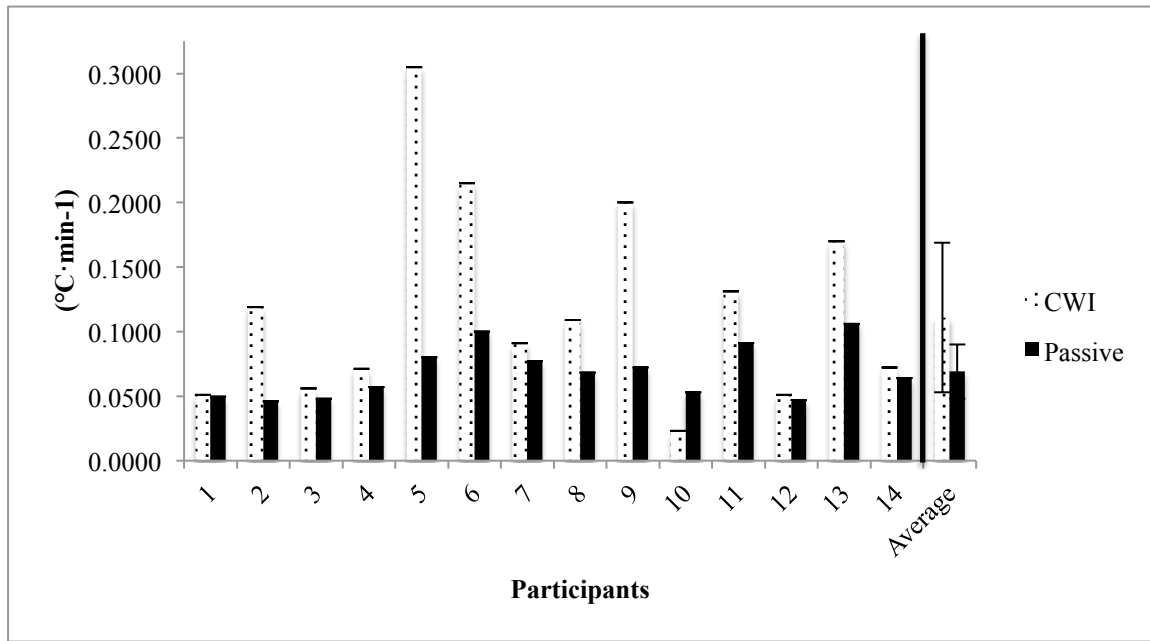


Figure 15-Comparison of cooling rate ($^{\circ}\text{C}\cdot\text{min}^{-1}$) of each participant for cold-water immersion (CWI) and passive.

Discussion

The purpose of this study was to investigate the efficacy of combinations of different body cooling modalities on mitigating the rate of rise of T_{re} . Passive cooling was less effective compared to all other conditions with the exception of HC alone and furthermore the greatest cooling rates were seen with CWI + HC ($0.13 \pm 0.07^{\circ}\text{C}\cdot\text{min}^{-1}$) and HC + IT ($0.13 \pm 0.07^{\circ}\text{C}\cdot\text{min}^{-1}$). Additionally, this study examined the additional benefit of the Temperature Management System to other commonly used modalities during 10-minutes of cooling. To this question, T_{re} decreased further than all other cooling modalities with the CWI + HC condition. This finding serves as a gateway for practical application in reducing core body temperature following exercise-induced hyperthermia in non-EHS populations. It should be noted that the present discussion addresses cooling rate and T_{re} , however, this study was part of a larger study that also included exercise performance and cognitive tasks. This data was collected at various points

throughout experimental trials, but was not one of the objectives of this study, and thus was not reported here.

Rectal Temperature and Cooling Rate

Head Cooling

A number of studies have been conducted investigating the effect of head cooling on thermal strain in a hot environment.¹⁰⁵⁻¹⁰⁷ While studies have been conducted examining head and neck cooling and its effect on perception of thermal strain, cognitive function, and exercise performance, to our knowledge there has yet to be a study investigating the effect of head cooling on T_{re} on exercise induced hyperthermia in human populations. As a result of our study, we observed that CWI + HC worked in tandem to produce the greatest overall cooling rate ($0.13 \pm 0.07^{\circ}\text{C}\cdot\text{min}^{-1}$) compared to passive rest ($0.07 \pm 0.02^{\circ}\text{C}\cdot\text{min}^{-1}$). Based on these cooling rates, after 20 minutes of cooling using these two methods would equate to a difference of 2.6°C versus 1.4°C or a person going from 106°F to 103.4°F with CWI + HC versus 106°F to 104.6°F with passive rest.

Brown et al.¹⁰⁵ evaluated the effects of head cooling on decreasing thermal strain in male pilots. Both studies were completed in challenging environmental conditions and incorporated equipment that impaired the body's ability to dissipate heat to the environment. T_{re} rise in the Brown et al.¹⁰⁵ study occurred as a result of participants passively heating for two hours while sitting in a 35°C environmental chamber in a clothing and equipment-laden ensemble. Worth noting, participants in our study removed all equipment prior to the initiation of cooling, whereas the equipment remained on in this study and participants were cooled during the trial. Brown et al.¹⁰⁵ observed increases in both aural and esophageal temperatures to approximately 38.0°C after two hours of passive heating. This is in contrast to our study where participants reached T_{re}

of 39.17 ± 0.46 °C via exercising in the heat. Brown et al.¹⁰⁵ observed that T_{re} rose to approximately 37.4°C when head cooling was implemented during the experimental trial. The authors noted that the rise in body temperature was attenuated by the introduction of head cooling. This is relevant to the present study because while head cooling does not have a role in the treatment of EHS, its use in mitigating rise of T_{re} calls for further investigation.

Nunnely et al.¹²⁴ performed a study looking at the effects of head and torso cooling on eight males during a simulated cockpit heat stress conditions. Similar to our study, they required participants to be in an equipment-laden situation. While this study included exercise, it was of brief duration and not comparable to our exercise protocol. Nunnely et al.¹²⁴ attributed their findings to being able to cool 3-4% of the body's surface area with the head-cooling cap. Participants in this study stated they did not feel the cap was very cool, which is similar to our findings. They also addressed a similar advantage to head cooling that we observed, and that is ease of application of head cooling in an equipment-laden individual. It is difficult to apply the findings of Nunnely et al.¹²⁴ to our study because of several key differences in methodology. Their study did not induce hyperthermia via exercise, and head cooling was applied during the trial as an evaluation of mitigating rate of rise instead of reducing T_{re} in an individual that is already hyperthermic. The participants in their study did not achieve a particularly high T_{re} (37.5°C). Additionally, they did not report cooling rate, so comparisons cannot be made in that regard. In the event this study had more key similarities it would have been beneficial to compare cooling rates. This is a study incorporating heat stress and head cooling which served as the immediate draw towards making comparisons between studies.

Frim¹⁰⁷ conducted a laboratory study looking at the role of head cooling in preventing heat strain in pilots. This was a similar study to that completed by Nunnely et al.¹²⁴ A major

difference in methodology once again rests with the role of passive heating versus exercise-induced hyperthermia. In contrast to our study, Frim¹⁰⁷ described lack of consistency in time of exposure to the heat, whereas all our participants displayed similar exercise time (55.0 ± 12.7 minutes). Final T_{re} in the Frim¹⁰⁷ study ranged from 37.2-37.8°C, further reiterating the differences in study design because participants did not get as hot through passive heating as they did through our exercise protocol ($39.17 \pm 0.46^\circ\text{C}$). It is difficult to compare the results of this study to ours; however, it is possible to see where room for further investigation exists regarding the role of head cooling is with respect to mitigating rate of rise of T_{re} . A cooling rate was not reported as a result of the timing of cooling used in this study protocol.

The present study is of special importance because of its identification of a possible cooling rate of head cooling. Previous studies have looked into the role of mitigating the rate of rise of T_{re} but have failed to determine the overall cooling potential of head cooling in an individual experiencing exercise-induced hyperthermia. The ease of application of head cooling likely serves as a gateway and catalyst for future research and its role in the mildly hyperthermic individual.

Cold-water Immersion

DeMartini et al.⁹⁰ looked at the effects of CWI on body temperature after exercise in the heat. Clear comparisons can be drawn between this study and the present. Both investigations implemented cooling for 10 minutes following an exercise protocol. In the DeMartini et al.⁹⁰ study, T_{re} reached $38.73 \pm 0.12^\circ\text{C}$, and in the present study T_{re} reached $39.17 \pm 0.46^\circ\text{C}$. In both studies, participants ended exercise at similar T_{re} . Significant differences in T_{re} after cooling were observed ($-0.65 \pm 0.29^\circ\text{C}$). An important consideration in comparing these studies is the difference between a field study and a laboratory study, such as what we performed.

Additionally, DeMartini et al.⁹⁰ circulated the water in the CWI tub, while we did not. DeMartini et al.⁹⁰ found a cooling rate of $0.06 \pm 0.04^{\circ}\text{C}/\text{min}$, whereas in the present study, we found cooling rates of $0.111 \pm 0.058^{\circ}\text{C}\cdot\text{min}^{-1}$. It is possible we saw an increased cooling rate as a result of a couple key differences. For one, participants in our study achieved a higher T_{re} at the onset of cooling and it is also likely that our participants had a higher skin temperature because of the equipment worn. This could have an influence on cooling rate because the body's thermoregulatory center may have observed the increases in T_{re} from our study to be approaching hazardous levels. Second, the temperature of the environment where cooling took place in our study was quite low ($22.4 \pm 1.6^{\circ}\text{C}$) and likely enhanced the cooling rate. It would be interesting in the future to examine the influence of the environment where the cooling takes place, indoor vs. outdoor and describe the potential benefits of indoor cooling when possible.

Proulx et al.¹⁵¹ looked at the effects of four different water temperatures of CWI on T_{re} in hyperthermic individuals following an exercise bout in the heat. This study produced some of the highest cooling rates on record. The authors evaluated the cooling rates of CWI at water temperatures of 2, 8, 14, and 20°C . The cooling rate ($0.35 \pm 0.14^{\circ}\text{C}/\text{min}$, $p=0.001$) was significantly greater with 2°C water in comparison to the other temperatures tested.¹⁵¹ This finding was attributed to the large temperature gradient between the skin and the water. In our study, this gradient was likely smaller due to warmer water temperature ($14.47 \pm 1.73^{\circ}\text{C}$) and how we did not record skin temperature for our purposes. Another important methodological difference is that Proulx et al.¹⁵¹ cooled participants until T_{re} reached 37.5°C , whereas we cooled our participants for 10 minutes or until T_{re} reached 38.0°C . In accordance with our study, T_{re} continued to drop even after the cooling treatment was completed. When participants were cooled in 14°C water, T_{re} continued to drop by $1.23 \pm 0.79^{\circ}\text{C}$ following the completion of

cooling.¹⁵¹ This is in comparison to the present study in which we observed a T_{re} after drop of $0.93 \pm 0.020^{\circ}\text{C}$.

Clements et al.⁸⁹ investigated the effects of CWI on cooling hyperthermic runners. Each participant in the study was cooled for 12 minutes. Similar to our study ($14.47 \pm 1.73^{\circ}\text{C}$), participants were immersed in water ($14.03 \pm 0.28^{\circ}\text{C}$) to the level of their clavicles.⁸⁹ CWI yielded a significantly greater ($p < 0.05$) cooling rate than passive rest.⁸⁹ The authors described a cooling rate of $0.16 \pm 0.0^{\circ}\text{C}/\text{min}$.⁸⁹ This study used a population different from that in the present study, in that the authors used trained endurance athletes. We elected to investigate the effects of various body cooling modalities on recreationally active individuals.

Forearm Ice Towels

DeMartinin et al.⁹⁰ additionally looked at the influence of buckets of ice water covering the forearms and feet to the midcalf on body temperature. In contrast to this study, we utilized towels rotated over the forearms after being soaked in ice water. Importantly, exercise ceased at similar T_{re} in both studies. Forearm ice towels may serve as an effective method of body cooling in mildly hyperthermic individuals.

Methodological Considerations and Limitations

The head-cooling device did not fit all the participants well. When the device began to compress the headpiece would often rise up on the participant instead of remaining in close contact with the head. Furthermore, the hair of the female participants impeded close contact of the cooling cap with the scalp. This may have affected the cooling rate for the female participants, although not statistically different than male cooling rates.

Taking these observations into account, opportunities for continued research include modifying the device to provide a more snug fit to the individual's head thus improving overall

contact with the cooling cap. This could mean using different materials and finding a way to ensure the cap remains in close contact with the skin even when the coolant is circulated and the cap expands. New models of this device include a neck collar that encircles the neck, helping to facilitate a better fit. It is imperative to note that in the present study, cooling occurred in exercise-induced hyperthermic individuals. While this allows us the opportunity to relate our results to equipment-laden individuals exercising in the heat, we may not apply our results to individuals failing to thermoregulate. Our participants remained normothermic throughout the duration of the study, which takes us back to why some individuals responded better to CWI than others. Another modification to the study would include increasing the duration of cooling. In the event we cooled participants for a longer duration, we may have been able to see more significant differences in cooling rate for each body cooling modality. Related to this point, is the fact that cooling occurred outside of the environmental chamber in a thermoneutral environment. This makes our results applicable to moving a hyperthermic individual from a hot environment to a thermoneutral environment to cool them. This could serve as another gateway to future studies by implementing cooling in a hot environment and observing differences in cooling rate. Additionally, this could be more reflective of a real-life situation in which a health care professional is likely to apply cooling in the field.

Moreover, this study occurred in a controlled, laboratory environment. This study could be repeated with a similar methodology in a field study. It is possible to utilize a similar protocol from this study and apply it to a field study. While it is considerably more difficult to control environmental conditions in a field study, it would serve as a gateway to more practical application of body cooling modalities in real-life situations.

Practical Applications

The overarching purpose of this study was to evaluate the ability of various body cooling modalities individually and in combination on lowering T_{re} . The participants in this study exercised in challenging environmental conditions ($38.5 \pm 1.5^{\circ}\text{C}$, $37.5 \pm 7.6\%$ RH). This is relevant because individuals often partake in exercise in the heat that places them at an increased risk of EHI. Therefore, we are able to apply our results to the population represented by our sample. The Temperature Management System® in particular is of interest due to its implications for use in the equipment-laden person. While this cooling modality does not yield cooling rates comparable to CWI, it may have other implications for use. The primary advantage of this head-cooling device is its ability to be used with ease in the equipment-laden individual. It may not always be possible to utilize CWI because of equipment, but in the event it is possible to access an individual's head, head cooling may act as a gateway to cooling to body. It is vital to address the fact that head cooling does not serve as a replacement for CWI as the “gold-standard” for EHS treatment.

There are a few clear advantages to using head cooling in a practical sense; however, they are coupled with several key drawbacks. One clear benefit of using head cooling in clinical practice is its ability to be used in an equipment-laden individual. With this device, it is possible to administer body cooling without removing all protective equipment. The head-cooling device operates at the push of a button, leaving the individual applying the device with the other responsibility of fitting the cap to the hyperthermic individual. Additionally, this device is extremely portable and that makes application of this cooling modality simple in field situations. As a result of the device's portability, the unit may be carried with an individual and cooling

could be applied throughout the activity. For these reasons, it is reasonable to recommend this device for use in the equipment-laden population, only in situations where EHS is not suspected.

While there are advantages to this device, it is vital to reiterate that head cooling is not a replacement for CWI in exertional heat stroke patients. Head cooling may act as a supplement to CWI but never should act as a substitute. The head cooling device did not appear to function as well with female participants despite lack of statistical differences between males and females. While the unit is fairly simple to transport, its components may be cumbersome to transport in the event a health care professional is also moving additional materials such as a medical kit. Also worth noting, the device has a battery flap that was prone to opening and exposing the batteries. This additional design flaw may lead to battery damage, and abnormal functioning of the device. Taking into consideration the benefits and drawbacks to head cooling, this device is recommended for use in a field setting as a supplemental form of body cooling.

Conclusions

Adding head cooling to common body-cooling modalities appears to serve as a supplement to CWI and may provide additional cooling benefits when compared to using body cooling modalities individually during the 10-minute cooling period. The cooling rate was greater for all body cooling modalities compared to passive rest. The only exception to this was head cooling. Cooling with CWI or CWI + HC resulted in lasting cooling effects after 40 minutes, which is likely due to T_{re} after-drop.

HUMAN PERFORMANCE LABORATORY MEDICAL HISTORY QUESTIONNAIRE

PLEASE ANSWER ALL OF THE FOLLOWING QUESTIONS AND PROVIDE DETAILS FOR ALL "YES" ANSWERS IN THE SPACES AT THE BOTTOM OF THE FORM.

64

[illegible]

- ## Reaction

- NO**

- ## Pipes

- | |
|--|
| |
| |
| |

Thyroid disease

- | |
|--|
| |
| |
| |
| |
| |

23. Has a doctor ever restricted your exercise because of an injury?

NO

24. Do you currently have any injuries that are bothering you?

25. Do you consider your occupation as?

Sedentary (no exercise)

Inactive-occasional light activity (walking)

Active-regular light activity and/or occasional vigorous activity (heavy lifting, running, etc.)

Heavy Work-regular vigorous activity

26. List your regular physical activities

Activity	How often do you do it?	How long do you do it?	How long ago did you start?

ADDITIONAL
DETAILS:

HUMAN PERFORMANCE LABORATORY PHYSICIAN CLEARANCE FORM

SUBJECT: _____

STUDY: _____

DATE: _____

☐

Cleared for participation in the above study

☐

Subject not yet cleared. Further clarification necessary (see below)

☐

Subject not yet cleared. Need to see subject (see reasons below)

☐

Subject not yet cleared. Subject needs clearance from personal physician (see notes below)

☐

Subject not cleared to participate in the study (see notes below)

NOTES

Signature: _____

Date: _____

Jeffrey M. Anderson, MD Medical Director

FOLLOW-UP (IF REQUIRED ABOVE)

☐

After review of the items noted above, the subject has been cleared for participation

☐

After review of the items noted above, the subject has not been cleared for participation

NOTES

Signature: _____

Date: _____

Jeffrey M. Anderson, MD Medical Director

Appendix B: Exercise History Questionnaire

Please answer the questions below to the best of your ability

1. How would you describe your current level of physical activity?
 - a. Not active
 - b. Occasionally active
 - c. Moderately active
 - d. Very active

2. How many days a week do you typically exercise?
 - a. 0
 - b. 1-2
 - c. 3-4
 - d. 4-5
 - e. 6-7

3. How long have you been exercising regularly?

Year(s)_____ Month(s)_____

4. What is your primary mode of exercise?
 - a. Endurance activities
 - b. Weight training
 - c. Team sports
 - d. A combination of activities
 - e. Not active

5. How would you rate your perceived level of exertion during exercise?

Light Fairly light Moderately Hard Hard

6. Do you typically have specific difficulties associated with exercise? If yes, please describe

7. What is your current exercise routine? Please describe briefly

Appendix C: Menstrual History Questionnaire

In this study we will be measuring your internal body temperature during exercise and cooling. Throughout the menstrual cycle your resting body temperature changes. Therefore, we need to understand where you are in your cycle in order to schedule your visits so all females in the study are in the same phase of the menstrual cycle during testing.

1. At present which statement best describes your menstrual cycle?

☐ I'm having regular periods (e.g., You can accurately predict when your next period will be. The date of my last period was ____/____/____.

☐ My periods are irregular (e.g., you cannot accurately predict when your next period will be) The date of my last period was ____/____/____

2. When you are having regular menstrual cycles, how many days are there between periods? _____

3. For how many days do you typically have your period? _____ Days

References

1. Casa D, Armstrong L, Carter R, Lopez R, McDermott B, Scriber K. Historical perspectives on medical care for heat stroke, part 1: Ancient times through the 19th century. *Athletic training and sports health care*. 2010;2(3):132-138.
2. Pandolf K, Burr R, Wenger C, Pozos R. Medical aspects of harsh environments. In: *Textbook of military medicine*. 2nd ed. ; 2002.
3. Casa D, McDermott B, Lee E, Yeargin S, Armstrong LM, CM. Cold water immersion: The gold standard for exertional heatstroke treatment. *Exerc Sport Sci Rev*. 2007;35(3):141-149.
4. Casa D, Armstrong L, Carter R, Lopez R, McDermott B, Sciber K. Historical perspectives on medical care for heat stroke, pat 2: 1850 through the present. *Athletic training and sports health care*. 2010;2(4):179-190.
5. Murray R. Nutrition for the marathon and other endurance sports: Environmental stress and dehydration. *Med Sci Sports Exerc*. 1992:319-323.
6. Murray R. Fluid needs in hot and cold environments. *Int J Sports Nutr*. 1995;5:62-73.
7. Brewster S, O'Connor F, Lillegard W. Exercise-induced heat injury: Diagnosis and management. *Sports Med Arthrosc Review*. 1995;3:206-266.
8. Haymes E, Wells C. Environment and human performance. In: *Human kinetics*. Champaign, IL: ; 1986:1-41.
9. Knochel J. Heat stroke and related heat stress disorders. *Dis Month*. 1989;35:301-377.

10. Bracker M. Hyperthermia: Man's adaptation to a warm climate. *Sports Med Dig.* 1991;13:1-2.
11. Johnson S, Ruhling R. Aspirin in exercise-induced hyperthermia: Evidence for and against its role. *Sports Med.* 1985;2:1-7.
12. Werner J. Central regulation of body temperature. In: *Exercise, heat, and thermoregulation.* Carmel, IN: Cooper Publishing.; 1993:7-35.
13. Kenny W. Thermoregulation during exercise in the heat. *Athl Ther Today.* 1996;1(13):16.
14. Nielsen B. Solar heat load: Heat balance during exercise in clothed subjects. *Eur.J.Appl.Physiol.* 1990;60:452-456.
15. Binkley H, Beckett J, Casa D, Kleiner D, Plummer P. National athletic trainers' association position statement: Exertional heat illnesses. *J.Athl Train.* 2002;37(3):329-343.
16. Grahn D, Dillon J, Heller H. Heat loss through the glabrous skin surfaces of heavily insulated, heat-stressed individuals. *Journal of Biomechanical Engineering.* 2009;131.
17. Galaski M. Hyperthermia. *J Can Athl Ther.* 1985;12:23-26.
18. Knochel J. Heat stroke and related heat stress disorders. *Dis Month.* 1989;35:301-377.
19. Pascoe D, Shanley L, Smith E. Clothing and exercise, I: Biophysics of heat transfer between the individual clothing and environment. *Sports Med.* 1994;18:38-54.

20. Brewster S, O'Connor F, Lillegard W. Exercise-induced heat injury: Diagnosis and management. *Sports Med Arthrosc Review*. 1995;3(206):266.
21. Haymes E, Wells C. Environment and human performance. In: *Human kinetics*. Champaign, IL: ; 1986:1-41.
22. Armstrong L. Keeping your cool in barcelona: The effects of heat humidity and dehydration on athletic performance strength and endurance. In: Colorado Springs, CO: United States Olympic Committee Sport Sciences Division; 1992:1-29.
23. Anderson G, Meneilly G, Mekjavic I. Passive temperature lability in the elderly. *Eur J Appl Physiol Occup Physiol*. 1996;73:278-286.
24. Candas V, Libert J, Vogt J. Influence of air velocity and heat acclimation on human skin wettedness and sweating efficiency. *J Appl Physiol*. 1979;47:1194-2000.
25. Berglund L, Gonzalez R. Evaporation of sweat from sedentary man in humid environments. *J Appl Physiol*. 1977;42:767-772.
26. Gonzalez-Alonso J, Mora-Rodriguez P, Below, E.F. Coyle. Dehydration reduces cardiac output and increases systemic and cutaneous vascular resistance during exercise. *J Appl Physiol*. 1995;79:1487.
27. Nybo L, Jensen T, Nielsen B, Gonzalez-Alonso J. Effects of marked hyperthermia with and without dehydration on VO₂ kinetics during intense exercise. *J Appl Physiol*. 2001;90:1057.

28. Gonzalez-Alonso J, Crandall CG, Johnson JM. The cardiovascular challenge of exercising in the heat. *J Physiol*. 2008;586(45).
29. Montain S, Coyle E. Influence of of graded dehydration on hyperthermia and cardiovascular drift during exercise. *J Appl Physiol*. 1992;73:1340-1350.
30. Adams W, Ferraro E, Huggins R, Casa D. The influence of body mass loss on changes in heart rate during exercise in the heat: A systematic review. *J Strength Cond Res*. 2014.
31. Huggins R, Martschinske J, Applegate K, Armstrong L, Casa D. Influence of dehydration on internal body temperature changes during exercise in the heat: A meta-analysis. *Med Sci Sports Exerc*. ;44(S5):791.
32. Casa D, Armstrong L, Hillman S, et al. National athletic trainers' position statement: Fluid replacement for athletes. *Journal of athletic training*. 2000;35(2):212-224.
33. Judelson D, Maresh C, Yamamoto L, et al. Effect of hystration state on resistance exercise-induced endocrine markers of anabolism, catabolism, and metabolism. *J Appl Physiol*. 2008;105:816.
34. Cheuvront S, Kenefick R. Dehydration: Physiology, assessment, and performance effects. *Compr.Physiol*. 2014;4(1):257.
35. Budd G. Wet-bulb globe temperature (WBGT)-its history and limitations. *jjsams*. 2007;7(3):2-31.

36. Armstrong L, Maresh C. The exertional heat illnesses: A risk of athletic participation. *Med Exerc Nutr Health*. 1993;2(125):134.
37. Gardner J, Kark J. Clinical diagnosis, management, and surveillance of exertional heat illness. In: *Medical aspects of harsh environments*. :231-262.
38. Gonzalez-Alonso J, Teller C, Anderson S, Jensen F, Hyldig T, Nielsen B. Influence of body temperature on the development of fatigue during prolonged exercise in the heat. *J Appl Physiol*. 1999;86:1032.
39. Caputa M, Feistkorn G, Jessen C. Effects of brain and trunk temperatures on exercise performance in goats. *Pflugers Arch*. 1986;406:184-189.
40. Fuller A, Carter R, Mitchell D. Brain and abdominal temperatures at fatigue in rats exercising in the heat. *J Appl Physiol*. 1998;29:1240-1249.
41. Galloway S, Maughan R. Effects of ambient temperature on the capacity to perform prolonged exercise in man. *Med Sci Sports Exerc*. 1997;29:1240-1249.
42. Gonzalez-Alonso J, Calbet J, Nielsen B. Metabolic alterations with dehydration-induced reductions in muscle blood flow in humans. *Eur Coll Sport Sci Meeting*. 1997:492-493.
43. Hales J, Hubbard R, Gaffin S. Limitation of heat tolerance. In: *Handbook of physiology*. 2nd ed. Bethesda, MD: Am Physiol Soc; 1996:285-355.
44. Latzka W, Sawka M, Montain S, et al. Hyperhydration: Tolerance and cardiovascular effects during uncompensable exercise-heat stress. *J Appl Physiol*. 1974;36:538-544.

45. MacDougall J, Reddan W, Layton C, Dempsey J. Effects of metabolic hyperthermia on performance during heavy prolonged exercise. *J Appl Physiol*. 1974;36:538.
46. Montain S, Sawka M, Cadarette B, Quigley M, McKay J. Physiology tolerance to uncompensable heat stress: Effects of exercise intensity, protective clothing, and climate. *J Appl Physiol*. 1994;77:216-222.
47. Sawka M, Young A, Latzka W, Neufer P, Quigley M, Pandolf K. Human tolerance to heat strain during exercise: Influence of hydration. *J Appl Physiol*. 1992;73:368-375.
48. Gonzalez-Alonso J, Calbet J, Nielsen B. Metabolic alterations with dehydration-induced reductions in muscle blood flow in humans. *Eur Coll Sport Sci Meeting*. 1997:492-493.
49. Pryor R, Casa D, Adams W, et al. Maximizing athletic performance in the heat. *Strength and Conditioning Journal*. 2013;35(6).
50. Marino FE. The critical limiting temperature and selective brain cooling: Neuroprotection during exercise? *Int J Hyperthermia*. 2011;27(6):582-590.
51. Caputa M, Feistkorn G, Jessen C. Effects of brain and trunk temperatures on exercise performance in goats. *Pflugers Arch*. 1986;406:184.
52. McConaghy F, Hales J, Rose R, Hodgson D. Selective brain cooling in the horse during exercise and environmental heat stress. *J Appl Physiol*. 1995;79(1849).
53. Fuller C, Baker M. Selective regulation of brain and body temperatures in the squirrel monkey. *Am J P Physiol Reg Integ Comp Physiol*. 1983;245:R293.

54. Baker M, Chapman L. Rapid brain cooling in exercising dogs. *Science*. 1977;195:781.
55. Nielsen B, Hales J, Strange N, Christensen N, Warberg J, Saltin B. Human circulatory and thermoregulatory adaptations with heat acclimation and exercise in a hot, dry environment. *J Physiol*. 1993;460:467.
56. Gonzalez-Alonso J, Teller C, Anderson S, Jensen, FB, Hyldig, T, Nielsen B. Influence of body temperature on the development of fatigue during prolonged exercise in the heat. *J Appl Physiol*. 1999;86:1032.
57. Parkin J, Carey M, Zhao S, Febbraio M. Effect of ambient temperature on human skeletal muscle metabolism during fatiguing submaximal exercise. *J Appl Physiol*. 1999;86:902.
58. Marino F. The critical limiting temperature and selective brain cooling: Neuroprotection during exercise? *Int. J Hyperthermia*. 2011;27:582.
59. Ray C, Gracey K. Augmentation of exercise-induced muscle sympathetic nerve activity during muscle heating. *J Appl Physiol*. 1997;82:1719.
60. Marino F. Methods, advantages, and limitations of body cooling for exercise performance. *Br.J.Sports Med*. 2002;36:89.
61. Nybo L, Secher N. Cerebral perturbations provoked by prolonged exercise. *Prog Neurobiol*. 2004;73:223.
62. Nybo L, Nielsen B. Hyperthermia and central fatigue during prolonged exercise in humans. *J Appl Physiol*. 2001;91:1055.

63. Gonzalez-Alonso J, Calbet J. Reductions in systemic and skeletal muscle blood flow and oxygen delivery limit maximal aerobic capacity in humans. *Circulation*. 2003;107:824.
64. Hargreaves M, Febbraio M. Limits to exercise performance in the heat. *Int J Sports Med*. 1998;19:115.
65. Gonzalez-Alonso J, Calbet J, Nielsen B. Muscle blood flow is reduced with dehydration during prolonged exercise in humans. *J Physiol*. 1998;513:895.
66. Walters T, Ryan K, Tate L, Mason P. Exercise in the heat is limited by a critical internal temperature. *J Appl Physiol*. 2000;89:799.
67. Fuller G, Carter R, Mitchell D. Brain and abdominal temperatures at fatigue in rats exercising in the heat. *J Appl Physiol*. 1998;84(877).
68. Nybo L. Hyperthermia and fatigue. *J Appl Physiol*. 2008;104:871.
69. Casa D, Becker S, Ganio M, et al. Validity of devices that assess body temperature during outdoor exercise in the heat. *J Athl Train*. 2007;42(3):333-342.
70. Casa D, M, BP, Lee E, Yeargin S, Armstrong L, Maresh C. Cold water immersion: The gold standard for exertional heatstroke treatment. *Exerc Sport Sci Rev*. 2007;35(3):141-149.
71. Armstrong L, ed. *Exertional heat illnesses*. 1st ed. Champaign, IL: Human Kinetics; 2003.
72. Epstein Y, Roberts W. The pathophysiology of heat stroke: An integrative view of the final common pathway. *Scand.J.Med.Sci.Sports*. 2011.

73. RAV-ACHA M, HADAD E, EPSTEIN Y, HELED Y, MORAN D. Fatal exertional heat stroke: A case series. *American Journal of the Medical Sciences*. 2004;328(2):84-87.
74. 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.
75. Casa D, Anderson J, Armstrong L, Maresh, CM. Survival strategy: Acute treatment of exertional heat stroke. *J Strength Cond Res*. 2006;20:462.
76. Casa D, Almquist J, Anderson S. Inter-association task force on exertional heat illnesses consensus statement. *NATA News*. 2003:329-342.
77. Kohagli M. *Heatstroke and temperature regulation*. Sydney, Australia: Academic Press; 1983.
78. Costrini A. Emergency treatment of exertional heatstroke and comparison of whole body cooling techniques. *Med Sci Sports Exerc*. 1990;22:15-18.
79. Armstrong L, Epstein Y, Greenleaf J, et al. American college of sports medicine position stand: Heat and cold illnesses during distance running. *Med Sci Sports Exerc*. 1996;28:i-x.
80. Armstrong L, Maresh C. Can humans avoid and recover from exertional heat stroke? *Adapt Biol Med*. 1999;2:344-351.
81. Larkin J. Treatment of heat-related illness. *JAMA*. 1981:245-281.
82. Strydom N. Heatstroke: Its definition, diagnosis, and treatment. *SA Med J*. 1982:537.

83. Drust B, Cable N, Reilly T. Investigation of the effects of the pre-cooling on the physiological responses to soccer-specific intermittent exercise. *Eur.J.Appl.Physiol.* 2000;81:11-17.
84. Golden F, Tipton M. *Human kinetics*. Champaign, IL: ; 2002.
85. Hall J. Prediction of tolerance in cold water and life raft exposure. *Aerosp Med.* 1972;43:281-286.
86. Smith DL, Fehling PC, Hultquist EM, et al. The effect of precooling on cardiovascular and metabolic strain during incremental exercise. *Appl Physiol Nutr Metab.* 2013;38(9):935-940.
87. Yeargin S, Casa D, McClung J, et al. Body cooling between two bouts of exercise in the heat enhances subsequent performance. *J Strength Cond Res.* 2006;20:383-389.
88. Proulx C, Ducharme M, Kenny G. Effect of water temperature on cooling efficiency during hyperthermia in humans. *J Appl Physiol.* 2003;94:1317-1323.
89. Clements J, Casa D, Knight J, et al. Ice-water immersion and col-water immersion provide similar cooling rates in runners with exercise-induced hyperthermia. *J.Athl Train.* 2002;37(2):146-150.
90. 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.

91. Buchheit M, Peiffer JJ, Abbiss CR, Laursen PB. Effect of cold water immersion on postexercise parasympathetic reactivation. *Am J Physiol Heart Circ Physiol*. 2009;296(2):H421-7.
92. Amorim FT, Yamada PM, Robergs RA, Schneider SM. Palm cooling does not reduce heat strain during exercise in a hot, dry environment. *Appl Physiol Nutr Metab*. 2010;35(4):480-489.
93. Grahn D, Cao V, Heller H. Heat extraction through the palm of one hand improves aerobic exercise endurance in a hot environment. *J Appl Physiol*. 2005;99(3):972-978.
94. Gao C, Kuklane K, Holmer I. Cooling vests with phase change materials: The effects of melting temperature on heat strain alleviation in an extremely hot environment. *Eur J Appl Physiol*. 2011;111(6):1207-1216.
95. Trbovich M, Ortega C, Schroeder J, Fredrickson M. Effect of a cooling vest on core temperature in athletes with and without spinal cord injury. *Top Spinal Cord Inj Rehabil*. 2014;20(1):70-80.
96. Kay D, Marino F. Fluid ingestion and exercise hyperthermia: Implications for performance, thermoregulation, metabolism and the development of fatigue. *Journal of sports sciences*. 2000;18(2):71-82.
97. Siegel R, Mate J, Watson G, Nosaka K, Laursen P. The influence of ice slurry ingestion on maximal voluntary contraction following exercise-induced hyperthermia. *European journal of applied physiology*. 2011;111:2517.

98. Siegel R, Mate J, Brearley M, Watson G, Nosaka K, Laursen P. Ice slurry ingestion increases core temperature capacity and running time in the heat. *Medicine and science in sports and exercise*. 2010;42(4):717.
99. Siegel R, Laursen P. Keeping your cool possible mechanisms for enhanced exercise performance in the heat with internal cooling methods. *Sports medicine (Auckland, N.Z.)*. 2012;42(2):89-98.
100. Mundel T, King J C, E, Jones D. Drink temperature influences fluid intake and endurance capacity in men during exercise in a hot, dry environment. *Experimental physiology*. 2006;91(5):925-933.
101. Lee J, Shirreffs S, Maughan R. Cold drink ingestion improves exercise endurance capacity in the heat. *Med Sci Sports Exerc*. 2008;40(9):1637.
102. Lee JK, Yeo ZW, Nio AQ, et al. Cold drink attenuates heat strain during work-rest cycles. *Int J Sports Med*. 2013;34(12):1037-1042.
103. Burdon C, O'Connor H, Gifford J, Shirreffs S, Chapman P, Johnson N. Effect of drink temperature on core temperature and endurance cycling performance in warm, humid conditions. *J Sports Sci*. 2010;28(11):1147-1156.
104. Burdon CA, Hoon MW, Johnson NA, Chapman PG, O'Connor HT. The effect of ice slushy ingestion and mouthwash on thermoregulation and endurance performance in the heat. *Int J Sport Nutr Exerc Metab*. 2013;23(5):458-469.

105. Brown G, Williams G. The effect of head cooling on deep body temperature and thermal comfort in man. *Aviat.Space Environ.Med.* 1982;53:583-586.
106. Nunneley S, Maldonado R. Head and/or torso cooling during simulated cockpit heat stress. *Aviat.Space Environ.Med.* 1983;54:496-499.
107. Frim J. Head cooling is desirable but not essential for preventing heat strain in pilots. *Aviation, Space, and Environmental Medicine.* 1989;60(11):1056-1062.
108. Mundel T, Bunn SJ, Hooper PL, Jones DA. The effects of face cooling during hyperthermic exercise in man: Evidence for an integrated thermal, neuroendocrine and behavioural response. *Exp Physiol.* 2007;92(1):187-195.
109. Vaile J, Halson S, Gill N, Dawson B. Effect of hydrotherapy on recovery from fatigue. *Int J Sports Med.* 2008;29(7):539-544.
110. House JR, Lunt H, Magness A, Lyons J. Testing the effectiveness of techniques for reducing heat strain in royal navy nuclear, biological and chemical cleansing station's teams. *J R Navy Med Serv.* 2003;89(1):27.
111. House JR, Holmes C, Allsopp AJ. Prevention of heat strain by immersing hands and forearms in water. *J R Navy.* 1997;83(1):26.
112. Whitish K, Ruby B, Gaskill S, Lankford D. Effect of the rapid thermal exchange (RTX) on power output, heart rate, and rectal temperature. *Med Sci Sports Exerc.* 2003;5:29.

113. Brade C, Dawson B, Wallman K, Polglaze T. Postexercise cooling rates in 2 cooling jackets. *J Athl Train*. 2010;45(2):164-169.
114. Szlyk P, Sils I, Francesconi R, Hubbard R, Armstrong L. Effects of water temperature and flavouring on voluntary dehydration in men. *Physiology & Behavior*. 1989;45(3):639.
115. Lee JK, Shirreffs SM, Maughan RJ. Cold drink ingestion improves exercise endurance capacity in the heat. *Med Sci Sports Exerc*. 2008;40(9):1637-1644.
116. Lee J, Maughan R, Shirreffs S. The influence of serial feeding of drinks at different temperatures on thermoregulatory responses during cycling. *Journal of sports sciences*. 2008;26(6):583.
117. Villanova N, Azpiroz F, Malagelada J. Perception and gut reflexes induced by stimulation of gastrointestinal thermoreceptors in humans. *The Journal of Physiology*. 1997;502:215.
118. Burdon CA, Hoon MW, Johnson NA, Chapman PG, O'Connor HT. The effect of ice slushy ingestion and mouthwash on thermoregulation and endurance performance in the heat. *Int J Sport Nutr Exerc Metab*. 2013;23(5):458-469.
119. Nielsen B, Hales J, Strange S, Christensen N, Warberg J. Human circulatory and thermoregulatory adaptations with heat acclimation and exercise in a hot, dry environment. *J Physiol*. 1993;460:467.
120. Mundel T, Hooper PL, Bunn SJ, Jones DA. The effects of face cooling on the prolactin response and subjective comfort during moderate passive heating in humans. *Exp Physiol*. 2006;91(6):1007-1014.

121. Shvartz E. Effect of a cooling hood on physiological responses to work in a hot environment. *J Appl Physiol.* 1970;29:36-39.
122. Dubois D, Dubois E. A formula to estimate the approximate surface area if height and weight be known. *Arch Intern Med.* 1916;17:863.
123. Gooden B. Why some people do not drown. hypothermia versus the diving response. *Med J Aust.* 1992;157:629-632.
124. Nunneley S, Maldonado R. Head and/or torso cooling during stimulated cockpit heat stress. *Aviat.Space Environ.Med.* 1983;54:496.
125. Armstrong L, Johnson E, Casa D, et al. The american football uniform: Uncompensable heat stress and hyperthermic exhaustion. *Journal of athletic training.* 2010;45(2):117-127.
126. Johnson EC, Ganio MS, Lee EC, et al. Perceptual responses while wearing an american football uniform in the heat. *J Athl Train.* 2010;45(2):107-116.
127. Lopez RM, Eberman LE, Cleary MA. Superficial cooling does not decrease core body temperature before, during, or after exercise in an american football uniform. *J Strength Cond Res.* 2012;26(12):3432-3440.
128. McCullough E, Kenny W. Thermal insulation and evaporative resistance of football uniforms. *Med.Sci.Sports Exerc.* 2003;35(5):832-837.
129. Fox EL, Mathews DK, Kaufman WS, Bowers RW. Effects of football equipment on thermal balance and energy cost during exercise. *Res Q.* 1966;37(3):332-339.

130. Mathews D, Fox E, Tanzi D. Physiological responses during exercise and recovery in a football uniform. *J Appl Physiol*. 1969;26(5):611-615.
131. Galloway S, Maughan R. Effects of ambient temperature on the capacity to perform prolonged cycle exercise in man. *Med.Sci.Sports Exerc*. 1997;29(9):1240-1249.
132. Armada-da-Silva P, Woods J, Jones, DA. The effect of passive heating and face cooling on perceived exertion during exercise in the heat. *European journal of applied physiology*. 2004;91(5-6):563-571.
133. Toner M, Drolet L, Pandolf K. Perceptual and physiological responses during exercise in cool and cold water. *Percept Mot Skills*. 1986;62(1):211-220.
134. Borg G. Perceived exertion as an indicator of somatic stress. *Scand J Rehabil Med*. 1970;2(2):92-98.
135. Noonan B, Mack G, Stachenfeld N. The effects of hockey protective equipment on high-intensity intermittent exercise. *Med.Sci.Sports Exerc*. 2007;39(8):1327-1335.
136. Kulka T, Kenny LW. Heat balance limits in football uniforms: How different uniform ensembles alter the equation. *Physician Sportsmed*. 2002;30(7):29-39.
137. Hitchcock K, Millard-Stafford M, Phillips J, Snow T. Metabolic and thermoregulatory responses to a simulated american football practice in the heat. *J Strength Cond Res*. 2007;21(3):710-717.

138. Armstrong L, Casa D, Millard-Stafford M, Moran D, Pyne S, Roberts W. American college of sports medicine position stand. exertional heat illness during training and competition. *Med Sci Sports Exerc.* 2007;39(3):556-572.
139. Hyashi C, Tokura H. Effects of head cooling on sweat rate in exercising subjects wearing protective clothing and mask for pesticide. *Appl Hum Scie J Physiol Anthr.* 1996;15(4):149-154.
140. Ansley L, Marvin G, Sharma A, Kendall MJ, Jones DA, Bridge MW. The effects of head cooling on endurance and neuroendocrine responses to exercise in warm conditions. *Physiol Res.* 2008;57(6):863-872.
141. Siegel R, Laursen PB. Keeping your cool: Possible mechanisms for enhanced exercise performance in the heat with internal cooling methods. *Sports Med.* 2012;42(2):89-98.
142. Aschoff J, Heise A. Thermal conductance in man: Its dependence on time of day and on ambient conditions. In: Itoh S, Ogata K, Yosimura H, eds. *Advances in climatic physiology.* Toyko: Igatu Shoin; 1972:334-348.
143. Kleitman N, Ramasroop A. Periodicity in body temperature and heart rate. *Endocrinology.* 1948;43:1-20.
144. Sleivert C, Cotter J, Roberts W, Febbraio M. The influence of whole-body vs. torso pre-cooling on physiological strain and performance of high-intensity exercise in the heat. *Comp Biochem Physiol A Mol Integr Physiol.* 2001;128(4):657-666.
145. McDermott B, Casa D, Ganio M, et al. Actual whole body cooling for exercise-induced hyperthermia: A systematic review. *J Athl Train.* 2009;44(1):84-93.

146. Lopez R, Zuri R, Jones L, Cleary M. Effects of a cooling vest on core and skin temperature following a heat stress trial in healthy males. *J Athl Train*. 2008;43:55-61.
147. Cheung S, Robinson A. The influence of upper-body pre-cooling on repeated sprint performance in moderate ambient conditions. *J Sports Sci*. 2004;22(7):605-612.
148. Duffield R, Dawson B, Bishop D, Fitzsimmons M, Lawrence S. Effect of wearing an ice cooling jacket on repeat sprint performance in warm/humid conditions. *Br.J.Sports Med*. 2003;37(2):164-169.
149. Tyler C, Wild P, Sunderland C. Practical neck cooling and time-trial running performance in a hot environment. *Eur.J.Appl.Physiol*. 2010;110(5):1063-1074.
150. Hasegawa H, Takatori T, Komura T, Yamasaki M. Wearing a cooling jacket during exercise reduces thermal strain and improves endurance exercise performance in a warm environment. *Strength Cond Res*. 2005;19(1):122-128.
151. Proulx C, Ducharme M, Kenny G. Effect of water temperature on cooling efficiency during hyperthermia in humans. *J Appl Physiol*. 2003;94:1317-1323.
152. Van Der Elst W, Van Boxtel P.J. Martin, Van Breuklein J.P. Gerard, Jolles J. The letter digit substitution test: Normative data for 1,858 healthy participants aged 24-81 from the maastricht aging study (MAAS): Influence of age, education, and sex. *Journal of Clinical and Experimental Neuropsychology*. 2006;28:998-1009.
153. Corrigan J, Hinkeldey M. Relationships between parts A and B of the trail making test. *J Clinical Psychol*. 1987;43(4):402-409.

154. Gaudino E, Geisler M, Squires N. Construct validity in the trail making test: What makes part B harder? *J Clin Exp Neuropsychol*. 1995;17(4):529-535.
155. Lezak M, Howieson D, Loring D. *Neuropsychological assessment*. New York, NY: Oxford University Press; 2004.
156. Reitan R. Validity of the trail making test as an indicator of organic brain damage. *Percept Mot Skills*. 1958;8:271-276.