

5-8-2014

The Influence of Intermittent Hand Cooling on Rectal Temperature and Performance in the Heat While Wearing an American Football Uniform

Michael W. Sundeen

University of Connecticut, msundeen.atc@gmail.com

Recommended Citation

Sundeen, Michael W., "The Influence of Intermittent Hand Cooling on Rectal Temperature and Performance in the Heat While Wearing an American Football Uniform" (2014). *Master's Theses*. 585.
https://opencommons.uconn.edu/gs_theses/585

This work is brought to you for free and open access by the University of Connecticut Graduate School at OpenCommons@UConn. It has been accepted for inclusion in Master's Theses by an authorized administrator of OpenCommons@UConn. For more information, please contact opencommons@uconn.edu.

**The Influence of Intermittent Hand Cooling on Rectal Temperature and
Performance in the Heat While Wearing an American Football Uniform**

Michael W. Sundeen

B.S. University of Northern Colorado 2010

A Thesis

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

At the

University of Connecticut

2014

Approval Page

Master of Science Thesis

The Influence of Intermittent Hand Cooling on Rectal Temperature and
Performance in the Heat While Wearing an American Football Uniform

Presented by:

Michael W. Sundeen, BS, ATC

Major Advisor _____

Douglas J. Casa, Ph.D., ATC, FACSM

Associate Advisor _____

Lawrence E. Armstrong, Ph.D., FACSM

Associate Advisor _____

Lindsay J. DiStefano, Ph.D., ATC

Associate Advisor _____

Rebecca L. Stearns, Ph.D., ATC

Associate Advisor _____

Robert Huggins, MEd, ATC

University of Connecticut

2014

Table of Contents

Abstract	5
Review of Literature	6
I. Background on Thermal Stress	
a. Exercise in the Heat	6
b. Hyperthermia Muscular Power and Modifications to Exercise	9
II. Football	14
a. Uncompensable Heat Stress	14
III. Performance	19
a. Hydration	19
b. Energy Systems Utilized during Football Activity	22
c. Football Specific Skills	22
IV. Methods for Heat Removal	24
a. Cooling Modalities and Cooling Rates	24
b. Mechanisms of Extremity Cooling	31
c. Hand Cooling	38
d. Opportunities for Cooling in Football	41
V. Gaps in the Literature	42
VI. Introduction	45
VII. Methods	47
a. Participants	47
b. Protocol	48
c. Familiarization Session	49
d. Hand Cooling Device	55
e. Testing Session	55
f. Data Reduction and Statistical Analysis	56
VIII. Results	57
a. Body Mass and Urine Specific Gravity	57
b. Rectal Temperature	59
c. Heart Rate	63
d. Performance Battery	65
e. Perceptuals	81
IX. Discussion	86
a. Rectal Temperature	86
b. Cardiovascular Responses	89
c. Performance Battery	91
d. Perceptuals	94
e. Methodological Considerations	96
f. Practical Applications	97
g. Conclusion	97

X. References	99
XI. Appendices	
Appendix A: Rating of Perceived Exertion Scale	114
Appendix B: Environmental Symptoms Questionnaire	116
Appendix C: Pain Intensity Scale	118
Appendix D: Thermal Scale	119
Appendix E: Thirst Scale	120
Appendix F: Fatigue Scale	121
Appendix G: Medical History Form	122

Abstract

The Influence of Intermittent Hand Cooling on Rectal Temperature and Performance in the Heat While Wearing an American Football Uniform

Sundeen MW, Huggins RA, Adams WM, Vandermark LW, Dempsey DM, Adams JE, Murray KP, Stearns RL, Casa DJ: Korey Stringer Institute, Department of Kinesiology, University of Connecticut, Storrs, CT.

Context: Fluid replacement and cooling during exercise have been shown to improve the ability to thermoregulate during exercise in the heat. Wearing an American football uniform increases heat storage and presents a challenge to optimal cooling. New modalities such as peripheral cooling may reduce core body temperature and improve performance in the areas of power, speed, agility, reaction time, and balance. **Objective:** To determine the effect of intermittent hand cooling with and without fluid replacement on sport-specific performance measures. **Design:** Randomized crossover design. **Setting:** Research laboratory. **Participants:** Thirteen males (age: 24 ± 3 yrs, height: 179 ± 5 cm, body mass: 82.6 ± 9.8 kg) performed three separate 90-minute treadmill exercise bouts in a hot environment (39°C , 40%RH) while wearing an American football uniform. **Intervention:** Participants were randomly allocated to hand cooling (HC), HC with fluid replacement (HCF), and no cooling (CON) in a counterbalanced order. Participants performed HC treatment using a negative pressure device (~ 140 mmHg) on 1 hand every 12th minute of exercise for 3 minutes. **Main Outcome Measures:** Participants completed sprint speed on a non-motorized treadmill (Sprint), foot speed count (Count), counter movement vertical jump (VJ), reaction time (React), and modified balance error scoring system (BESS) performance battery before (PRE) and after (POST) exercise. T_{RE} was measured PRE and POST exercise. A repeated measure ANOVA for condition by time with post-hoc Bonferroni tests set at ($\alpha \leq 0.05$) were utilized to compare differences. Mean differences with 95% confidence intervals, effect sizes (MD, 95%CI, ES) and percent change in performance measures (% Δ) PRE to POST (% Δ , 95%CI, ES) were used to compare performance across conditions. **Results:** POST T_{RE} for HCF ($38.64 \pm 0.39^\circ\text{C}$) was significantly different than CON ($39.24 \pm 0.49^\circ\text{C}$; $p=0.005$, $ES=0.61$) but not HC ($38.86 \pm 0.45^\circ\text{C}$; $p=0.66$, $ES=0.25$). POST T_{RE} for HC was not different than CON ($p=0.111$, $ES=0.41$). Sprint % Δ [HCF-CON] was 4.99%, (95%CI= -0.05 to 10.04), $ES=0.73$, [HCF-HC] was 2.12%, (95%CI= -2.93 to 7.17), $ES=0.20$, and [HC-CON] was 2.88%, (95%CI= -2.17 to 7.92), $ES=0.26$. Count % Δ [HCF-CON] was 3.77%, (95%CI= -2.77 to 10.31), $ES=0.31$, [HCF-HC] was 2.06%, (95%CI= -8.59 to 4.48), $ES=0.25$, and [HC-CON] was 5.83%, (95%CI= -0.71 to 12.37), $ES=0.44$. React % Δ for [HCF-CON] was -5.96%, (95%CI= -14.10 to 2.17), $ES=0.51$, [HCF-HC] was -7.10%, (95%CI= -15.23 to 1.03), $ES=0.46$, and [HC-CON] was 1.14%, (95%CI= -6.99 to 9.27), $ES=0.08$. BESS % Δ score [HCF-HC] was -21%, (95%CI= -53 to 12), $ES=0.46$, [HC-CON] was -17%, (95%CI= -49 to 16), $ES=0.27$, and [HCF-CON] was -37%, (95%CI= -70 to -5), $ES=0.53$. CMVJ Height % Δ [HCF-HC] was 2%, (95%CI= -9 to 13), $ES=0.18$, [HC-CON] was -1%, (95%CI= -12 to 10), $ES=0.08$, and [HCF-CON] was 1%, (95%CI= -10 to 12), $ES=0.11$. CMVJ VGRF % Δ [HCF-HC] was 3%, (95%CI= -4 to 10), $ES=0.41$, [HC-CON] was 2%, (95%CI= -5 to 9), $ES=0.14$, and [HCF-CON] was -1%, (95%CI= -10 to 12), $ES=0.40$. **Conclusions:** HCF significantly reduced T_{RE} POST. Furthermore, HCF resulted in improvements in % Δ for Sprint and React compared to CON. Reduced thermal strain in the HCF condition may have allowed for a greater effort during performance tasks POST.

I. Background on Thermal Stress

A. Exercise in the Heat

The body's physiological processes are drastically influenced by hot and humid environments. Often these environmental conditions lead to a state of hyperthermia where the temperature gradient between the skin and air decreases resulting in a reduction of heat removal from the body. As this heat is continuously stored within the body, core temperature (T_{RE}) increases and may rise to levels in excess of 40°C [104°F] that can impact the exercising individual. Two theories prevail as an explanation for this impact during exercise. The first, states that there is a critical limiting temperature (40° C [104° F]) that once reached leads to the cessation of exercise due to a steady detriment of performance.¹ The second theory states that the athlete's brain anticipates reaching this critical limiting temperature, and alters exercise accordingly to avoid hyperthermia. This allows the athlete to continue exercise, albeit at a lower intensity.² Whether exercise is ceased from the former or the latter, it occurs as a protective mechanism precluding the onset of exertional heat illness (EHI). These protective mechanisms, largely based on muscle temperature, inherently negatively influence performance especially in the areas of muscular power and strength¹⁻⁵ and are further exacerbated in the presence of dehydration and cardiovascular (CV) strain.¹⁻⁹ In an attempt to prevent these performance decrements, strategies to improve performance during exercise have focused on the improvement of both thermoregulatory and cardiovascular status.¹⁰ That being said, it is well supported through research that an optimal body temperature range exists for maximum performance in skeletal muscle.^{5,11} If the temperature exceeds 38-40°C a significant decrease in muscle power, strength and an increase in fatigue has been observed.¹² In order to combat this natural response to the internal production of heat in hot and humid conditions, the body must remove heat to maintain thermoregulation and subsequent performance during exercise.

The body is equipped with mechanisms to remove excess heat from the body. Heat loss occurs via 4 methods: conduction, convection, radiation, and evaporation. Conduction allows heat to move down its thermal gradient to a surrounding medium.¹³ Convective heat loss occurs when fluid moves across the skin removing heat from the body. Radiative heat loss occurs when heat is directly given off by the body to the surrounding environment. Evaporation is the body's primary means for heat removal and is defined as the removal of heat through moisture in the skin to the surrounding environment via sweating. In order to better understand evaporative cooling it is important to note that much of the internal heat produced is generated by active muscle, and blood is the media through which heat is transferred and redistributed to the periphery. Vasodilation of vascular structures occurs and once blood arrives to the skin via capillaries, the moisture in the dermal layers draws heat to the surface of the skin. Once the sweat appears on the surface of the skin, it is then evaporated removing heat with it. The movement of metabolic heat to the environment is important to an athlete's performance and safety. As long as a positive temperature gradient is present, sweat will evaporate from the skin releasing heat from the body, however in many environmental conditions this is less effective.

When the environmental temperature is lower than skin temperature, movement of heat from the body to the environment is facilitated. Larger temperature gradients between the skin and the surrounding environment promote the transfer of heat from the source to the cooler environment than environments where small temperature gradients exist. When water saturation of the air or humidity levels rise, water collects on the skin surface instead of being evaporated, and the body's ability to release heat decreases causing T_{RE} to increase.¹³ Protective equipment can create this type of microclimate directly over the skin of an athlete. Heat is unable to escape and moisture forming on the skin both create a high temperature just above the skin and increases humidity levels.¹⁴ This environmental factor leading to a severe heat stress situation and taxing the physiological processes during exercise can quickly lead to serious cellular changes.

In response to excessive heat stress the body will mobilize pro and anti-inflammatory mediators in an attempt to promote beneficial physiological changes allowing the body to adapt to future stressors. Often when excessive hyperthermic conditions occur, the body can cause a disruption that leads to a cascade of negative reactions at a cellular level. If the heat stress dosage is too large (i.e. exertional heatstroke) endotoxemia may occur. Endotoxemia occurs when endotoxins are released from the gut into the blood stream which may result in septic shock.^{13, 15} The mechanism behind endotoxemia occurs when a sympathetic response known as splanchnic vasoconstriction decreases blood flow to the gut in an attempt to increase blood flow to the periphery.¹³ The cascade effect occurs when endotoxins enter the blood stream in response to increased levels of inflammatory cytokines that cause fever, nausea, vomiting, diarrhea, headache, tissue breakdown, shock or death.¹³ This environment within the body causes cells to become inflamed and lysed. The only way to stop this cascade from becoming widespread throughout the body is to remove the heat from the body as quickly as possible. Hence the longer the T_{RE} remains above the critical threshold for enzymatic processes, the greater the detriment to the body.^{5,16,17} In order to prevent the body from ever reaching endotoxic levels, the body can undergo physiological adaptations through heat acclimatization.

Heat acclimatization is the process by which the body adapts to thermal stress and undergoes physiological adaptations that are advantageous to heat removal. Such adaptations include increased sweat rate, reduced resting core body temperature, decreased heart rate, increased blood volume, and increased electrolyte concentration. Implementing heat acclimatization is a valuable recommendation for proper training when in a hot environment. Heat acclimatization has been a focus to increase one's ability to cope with exercise in the heat.⁹

Humans regulate T_{RE} very well in warm climates¹⁸ and through many physiologic mechanisms, beginning in the brain, maintain a balance of temperature between 35°C and 39°C.¹³ However, above

ambient temperatures of 25 °C T_{RE} raises proportionally to the increase in ambient temperature.¹³ The physiological responses to exercise in the heat are venous compliance in the skin, causing a redistribution of blood to the periphery.¹³ The mechanisms evoking cardiovascular (CV) drift may cause a decrease in central blood volume, a reduction of venous return to the heart which in turn decreases cardiac filling and stroke volume in the heart, and increased heart rate in an attempt to maintain an adequate cardiac output for exercise to offset the decrease in stroke volume.^{19,20,21,22,23-25} Some studies have shown that the degree of CV drift during prolonged exercise can be manipulated by fluid ingestion²⁶, ambient temperature²⁷, exercise intensity²⁸, and cooling methods²⁹. However, very little research has investigated the effect of CV drift on performance. We know that as environmental temperatures a subsequent increase in T_{RE} occurs, causing important protective measures by the thermodynamic system. However, these can be a detriment to performance unless acclimatization has occurred over time. This gives the modes of heat transfer an increased ability to regulate temperature, with evaporation being the primary method of heat transfer with the environment. If exercise is performed in hot and humid environments it is understood that an extent of hyperthermia will ensue, so in order to find what cooling mechanisms may mitigate T_{RE} in these situations, we must understand what drives the adaptations during exercise in the heat.

B. Hyperthermia, Muscular Power and Modifications to Exercise

As discussed previously, two contrasting perspectives emerge when investigating the body's reaction to hyperthermia. One view, the critical internal temperature hypothesis, has established that fatigue is a resultant of decreased force production once T_{RE} rises above 40°C^{3,14,30-32} and the supraspinal neural activation of muscle motor units reduce. The contrasting opinion states that motor unit activation and performance are reduced before the body temperature even reaches a critically high level.^{15,33-35} The following studies offer evidence in support of the critical limiting temperature

hypothesis. Nybo et al.³ concluded that subjects who cycled for one hour in a cool environment had increased central activation (82% and 54% respectively) compared to the hyperthermic group (Figure 1). Additionally the cool environment resulted in increased prolonged maximum voluntary contraction (MVC) with either the quadriceps or hand grip. (Figure 1 and Figure 2) Nybo et al. concluded that the attenuated force production in the hyperthermic group is associated with a reduction in the voluntary activation percentage. (See Figure 1)

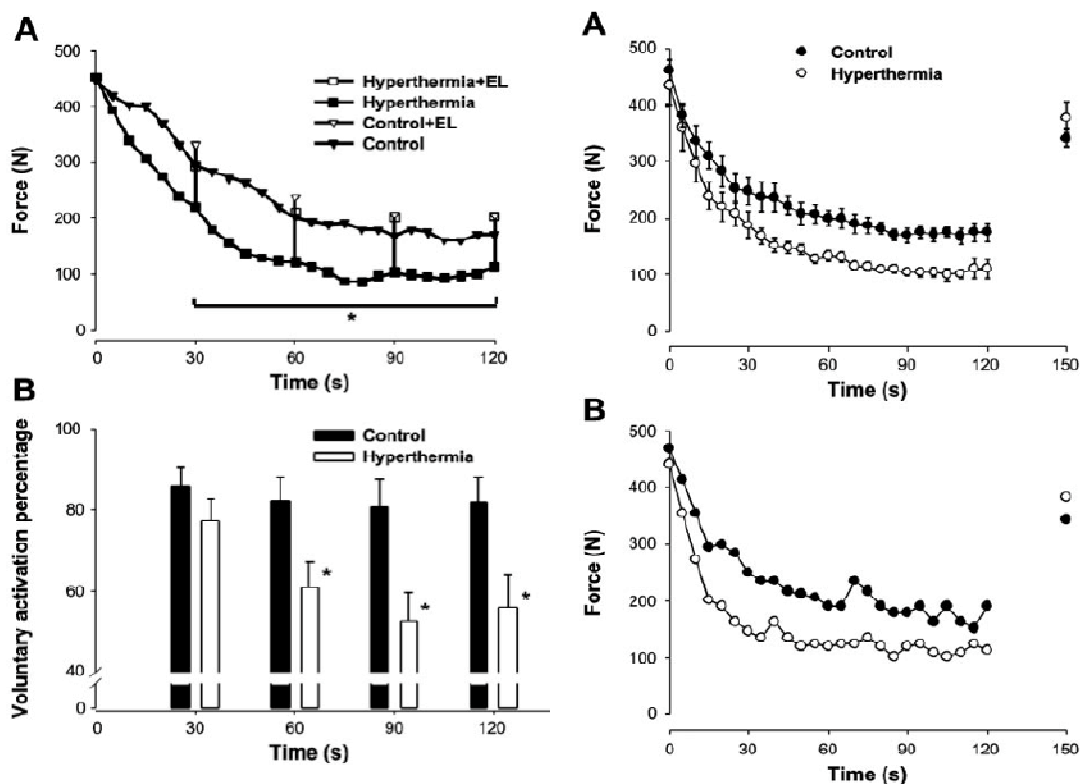


Figure 1- Changes in force (A) and voluntary activation percentage (B) during 2 min. of sustained MVC with the knee extensors during hyperthermia and control. Electrical central activation data are means \pm SE and * significantly lower than control stimulation (EL) was superimposed every 30 s to assess the degree of (P < 0.05). **Figure 2-** A: changes on force during 2 min of sustained maximal handgrip contraction with or without exercise-induced hyperthermia. Data are means \pm SE for 8 subjects. B: changes in force during 2 min of sustained maximal handgrip contraction with or without exercise-induced hyperthermia (mean of 2 subjects). From Nybo L, Nielsen B. Hyperthermia and central fatigue during prolonged exercise in humans. *J Appl Physiol.* 2001;91(3):1055-1060.

In further support of the critical temperature theory, Todd et al.⁴ confirmed the findings of Nybo et al.³, showing that voluntary activation decreased in a hyperthermic state (38.5°C) compared to a normal state (37°C). The decrease in isometric contraction was due to an adaptation in the muscle (20% increase in peak relaxation rate) that is not matched with any adaptation of descending voluntary drive being transmitted from the motor cortex. When a magnetic stimulation of the motor cortex was induced during maximum voluntary contraction it showed a twitch of 50% greater contraction. It was concluded that drive is regulated by brain centers and cortical output as a protective mechanism while exercising in the heat. The results of both studies^{3,4} observed that the body withholds maximal effort because it will cause further stress to a taxed thermoregulatory system (Figure 3). The body must maintain central blood volume and both active muscles and the skin require a large volume, so if exercise continues then one of the two will suffer leading to issues mentioned previously. When we apply these research findings to sports such as American Football it can be theorized that central fatigue due to an elevated T_{RE} may occur after a long duration of play on the field. The body recognizes that the stress will continue to increase if intensity remains constant and inhibits the transmission of the same neural drive as a protective mechanism. Unless this athlete is removed from the field and cooled, the subsequent play on the field will lack the same power, speed, or agility placing them at a competitive disadvantage.

In contrast some studies have found evidence that pacing strategies may occur before reaching a critical limiting T_{RE} . This forms the foundation of the hypothesis for a teleoanticipatory system. The brain anticipates the end point of exercise (teleo = “end”) and from there decides on exercise intensity by utilizing a specific pacing strategy in order to maintain homeostasis of the thermodynamic system. Morrison et al.¹⁵ concluded that T_{RE} alone causes a decrease in muscle strength during passive heating and cooling. Subjects were seated and core temp was elevated via environmental conditions from 37.4°C to 39.4°C and then cooled by a liquid conditioning garment back to baseline, during which MVC

was measured throughout. Additionally, a T_{RE} of 39.4°C reduced both voluntary activation (VA) and maximum voluntary contraction (MVC) by (11% and 13% respectively) (Figure 3). However, rapid skin cooling did not restore the measures of CV strain and psychophysical strain to baseline. Morrison et al. concluded that T_{RE} must return to normothermic levels before VA and MVC increases due to efficient contractile characteristics of the muscle (Figure 3 and Figure 4). This conclusion supports the paleoanticipatory mechanism because it is not the "real time" core body temperature that triggers a decrease in muscle function, but the body's understanding of the stress placed on it.

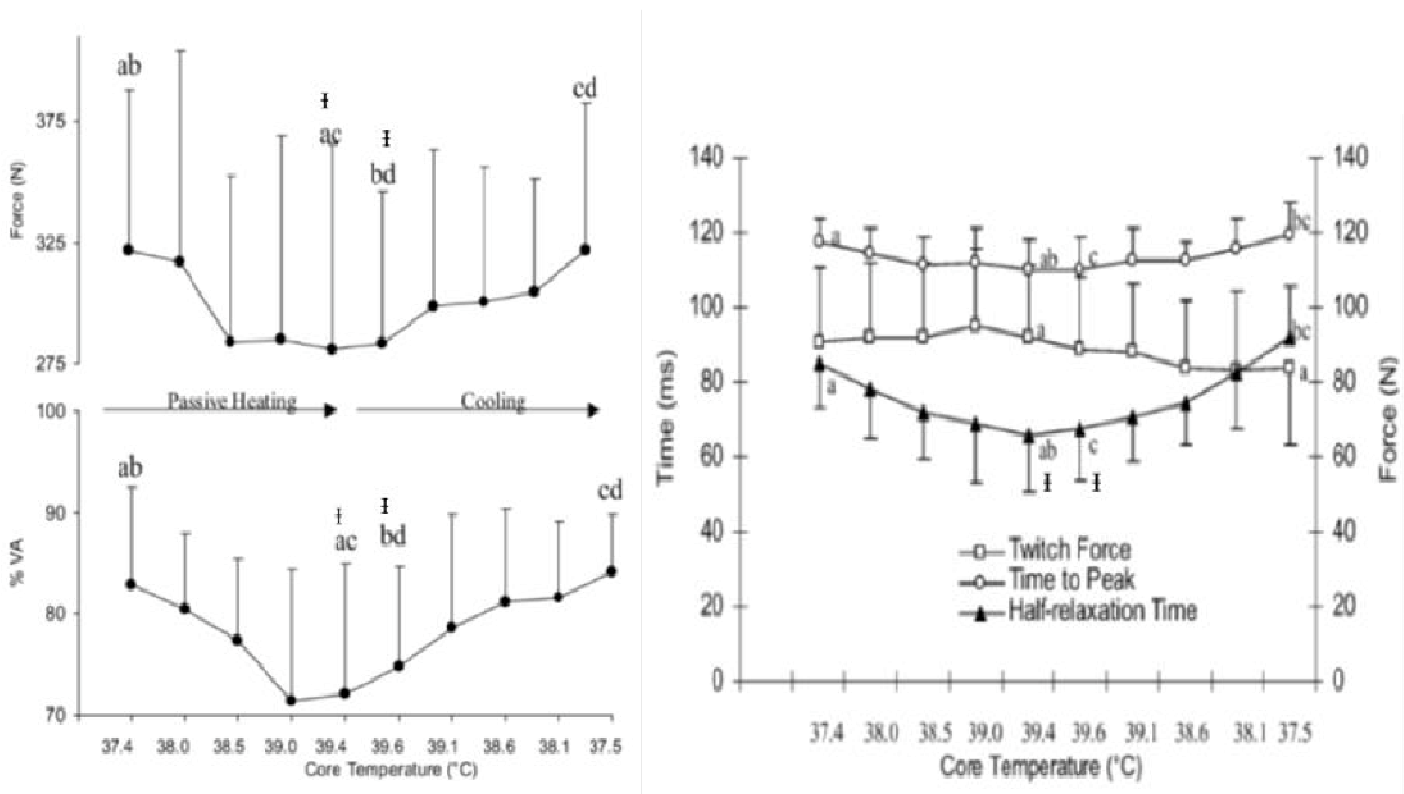


Figure 3- (Left) Knee extension maximal isometric force production (MVC; top) and voluntary activation (VA; bottom) during passive heating and cooling. Matching letters indicate significant differences ($P < 0.001$). $n = 22$ except ($\square n = 17$). **Figure 4-** (Right) Contractile characteristics of knee extensors during passive heating and cooling. Matching letters indicate significant differences ($P < 0.001$). $n = 22$ except ($\square n = 17$). From Morrison S, Sleivert GG, Cheung SS. Passive hyperthermia reduces voluntary activation and isometric force production. *Eur J Appl Physiol.* 2004;91(5-6):729-736.

Supporting the previously mentioned study, Tucker et al.³⁴ investigated pacing strategy in male cyclists and found that during self-paced cycling of 20-km, power output and electromyographic activity in the quadriceps decreased before there was an abnormal increase in T_{RE} , HR, or RPE. In the hot trial (ambient temp 35°C) EMG of the quadriceps were significantly lower at 10 km and 20 km marks, and power output was significantly reduced in the period from 80% to 100% of the trial duration. Thus, they concluded that the reduction in performance prior to an abnormal increase in HR, rectal temp, or RPE was part of an anticipatory response, adjusting muscle recruitment, and power output in order to reduce intrinsic heat production.¹⁹ This being done in order to ensure that thermal homeostasis is maintained during exercise in the heat.

Although not clearly understood which of the two mechanisms has the most effect on the body's reaction to exercise in uncompensable heat stress, Cheung et al. believes that the two models are complimentary to one another.³⁶ The studies that offer methodology of fixed workload would be more sensitive to the critical limiting temperature model because the body is pushed to a physiological maximum, thus utilizing the “emergency off” mechanism to protect the body.³⁶ When “real-world” practical methodology offers race like pace or self paced exercise it would lend itself to be more sensitive of the anticipatory down-regulation model. With both models being valid, why isn't it reasonable that each serve together for redundancy purposes in the body. This study has its roots in a practical setting of football athletes we feel the anticipatory down regulation model may be of greater importance, so this is what drives the exploration of intermittent cooling modalities that offer a mechanism for altering the anticipated stress by the brain during exercise. Heat removal from the body's core is valuable to muscular performance through the reduction of T_{RE} . Furthermore, it reduces the body's perception of its environment enabling for exercise to continue. Cooling the body should attenuate the actual T_{RE} and prevent reaching the point at which fatigue or exhaustion ensues. Cooling causes the body to perceive its environment as cooler, both leading to improvement in physiological

function, perceived exertion and muscle strength. This mechanism is both good and bad, by diminishing the perception of heat stress it may lead to improved performance capability. However, this can also lead to serious ramifications because with an individual feeling less heat stress and exercising at a constant rate, T_{RE} may still be increasing to dangerous levels.

II. Football

A. Uncompensable Heat Stress

The ability to compensate or to maintain one's internal body temperature during exercise in the heat has been shown to be critical for performance. When the amount of heat gain equals the amount of heat loss the body is said to be in a compensable heat stress (CHS) situation however, when the heat gain exceeds the amount of heat loss, the body is in an uncompensable state. Uncompensable heat stress (UCHS) is defined as an environment where the heat stress index (HSI) is equal to 1.0; ($HSI = \text{evaporation required} / \text{evaporation max OR } E_{req}/E_{max}$). When the HSI is equal to 1.0, there is a resultant net storage of heat in the body and therefore is unable to thermoregulate appropriately.

During uncompensable heat stress the evaporative heat loss required to maintain a steady state exceeds the maximal evaporative capacity of the environment and the body stores heat. In order to fully understand heat loss versus heat gain an understanding of the heat balance equation is essential.

Heat Balance Equation: $S=M-W\pm(E\pm R\pm C\pm K)$

- S = A positive S value represents the gain in heat storage by the body where a negative value represents net heat loss.
- M = the metabolic heat production and is determined by indirect calorimetry.
- W = the external work performed by the person

- R= the radiant heat exchange
- C= the conductive exchange
- K= the convective exchange
- E = the evaporative exchange which is divided into wet and dry
 - Dry is dependent on the temperature gradient
 - Wet loss is the evaporation of water or sweat.

Due to the protective equipment used and the prevalence of athletes with larger ratios of mass relative to surface area, football players reach a state of uncompensable heat stress quicker than most athletes.³⁷ It has been determined that while wearing full football equipment, uncompensable heat stress can occur in as little as 26°C and 52% relative humidity.³⁸ The microclimate created by the protective equipment worn during football increases humidity and temperature close the skin, thus reducing heat dissipation via radiation, convection, and evaporation.^{14,16,17,38-42} As previously discussed, these heat loss mechanisms are an integral part of thermoregulation during exercise. It can be postulated that with the combination of these factors, constant exercise intensity will lead to continuous increase in T_{RE} ultimately leading to exercise cessation via exhaustion or serious medical emergency.

Although not continuous, the high intensity play during a football game or practice places high demands on the energy systems of the body. An issue arises because it has been shown that during the lower intensity time points (rest periods) T_{RE} does not decrease, instead it plateaus then continues to rise again when the intensity of exercise increases.⁴³

The equipment worn in football has a profound effect on the athlete's ability to dissipate heat. Hitchcock et al.³⁷ confirmed this in their investigation of the energy cost of offensive lineman (OL) during a simulated football practice while wearing four separate combinations of football equipment. During

the testing session subjects performed a treadmill protocol, wall sits, and agility exercises with intermittent rest periods throughout. They found that T_{RE} increased (Figure 5), relative exercise intensity was significantly higher (Figure 6) and HR was maintained at 79% HRmax (Figure 7). This study also validated previous research that blood lactate levels increase three- to fivefold above baseline during a football game ($5.5 \text{ mmol}\cdot\text{L}^{-1}$).⁴³ It was also found that high intensity OL drills has the greatest impact on T_{RE} .

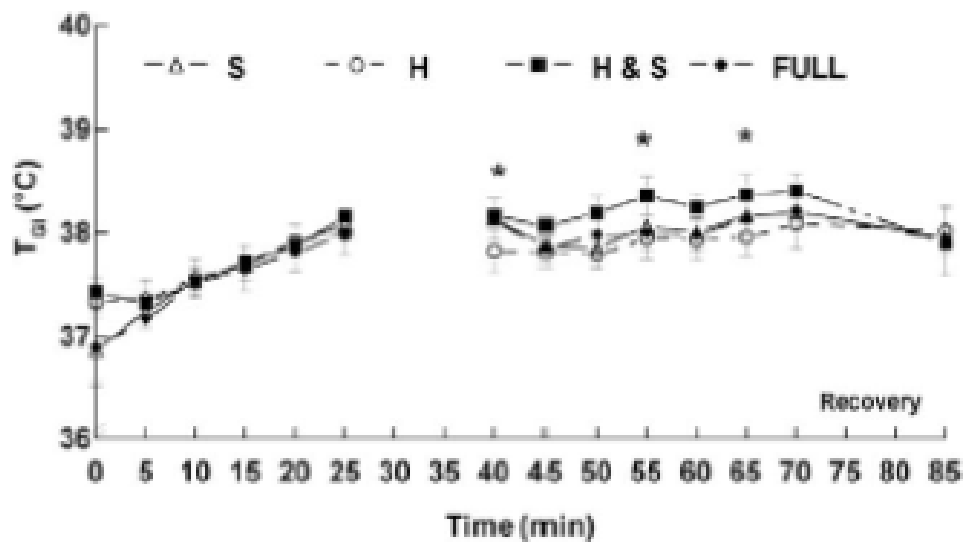


Figure 5- Mean \pm SD temperature in the gastrointestinal tract (TGI) during the football protocol while wearing different football ensembles (S= shorts only, H= helmet only, HS = helmet and shoulder pads added, FULL= helmet and shoulder, thigh, and hip pads added). *Significantly higher value ($p < 0.05$) for HS compared to H. From Hitchcock KM, Millard-Stafford ML, Phillips JM, Snow TK. Metabolic and thermoregulatory responses to a simulated American football practice in the heat. *J Strength Cond Res.* 2007;21(3):710-717.

In a study by Armstrong et al.¹⁴ a controlled exercise intensity design was used to measure physiologic strain and investigate critical internal temperature during exercise with full pads, partial pads, and a control condition of no pads (Figure 8). In this study subjects wearing full football pads reached a point of uncompensable heat stress. This was seen from the data points showing a continuous rise in T_{RE} (full pads condition) instead of a plateau, seen in the partial pads and control conditions (Figure 8). The physiologic strains placed on these subjects were tremendous. Mean final HR in full pads, partial pads, and control were 180 beats/min, 178 beats/min, and 164 beats/min

respectively indicating CV strain (Figure 9). This, in conjunction with a noted drop in systolic blood pressure during the treadmill walking portion of the test, suggests that cardiac filling and stroke volume decreased. At the point of exhaustion in hyperthermic conditions, there are large amounts of CV strain placed on the body.

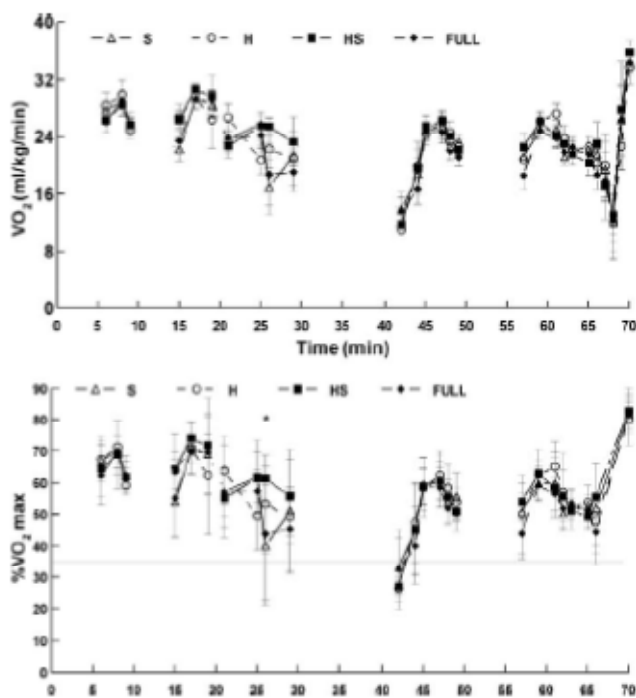


Figure 6- Mean \pm SD relative exercise intensity expressed as the percentage of maximal oxygen uptake and oxygen uptake relative to body weight during the football protocol while wearing different football ensembles (S= shorts only, H= helmet only, HS = helmet and shoulder pads added, FULL= helmet and shoulder, thigh, and hip pads added). *Significantly higher value ($p < 0.05$) value for HS compared to H and S. The horizontal line indicates the assumed relative exercise intensity (35% $\text{VO}_{2\text{max}}$) used in heat balance equations for football. From Hitchcock KM, Millard-Stafford ML, Phillips JM, Snow TK. Metabolic and thermoregulatory responses to a simulated american football practice in the heat. *J Strength Cond Res.* 2007;21(3):710-717.

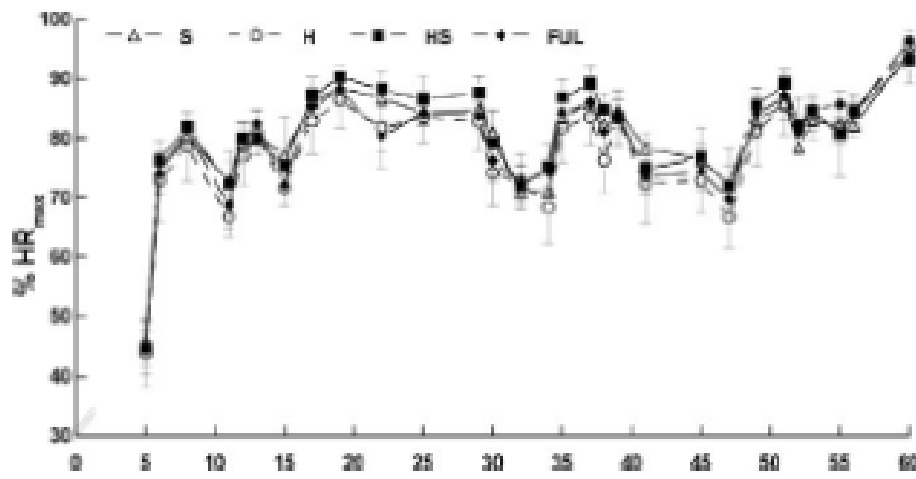


Figure 7- Mean \pm SD percentage heart rate relative to maximum (%HRmax) during the football protocol while wearing different football ensembles (S= shorts only, H= helmet only, HS = helmet and shoulder pads added, FULL= helmet and shoulder, thigh, and hip pads added). *Significantly higher value ($p < 0.05$) for HS compared to H. From Hitchcock KM. Millard-Stafford ML. Phillips JM. Snow TK. Metabolic and thermoregulatory responses to a simulated

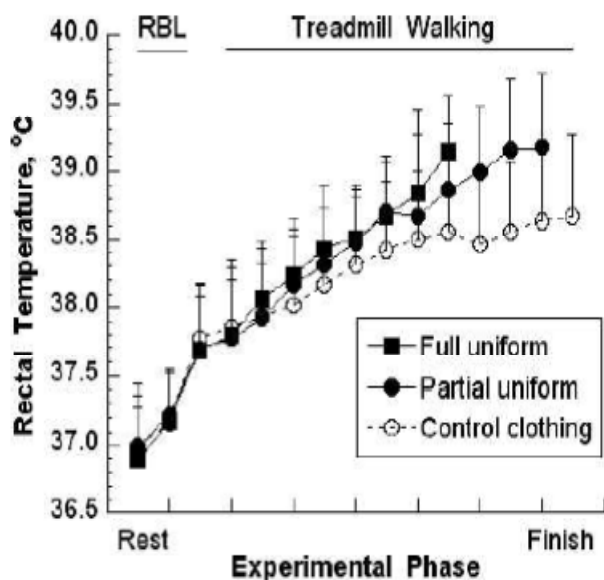


Figure 8- Rectal temperature responses (mean \pm SD) during repetitive box lifting (RBL), recovery, and treadmill exercise while wearing 3 different clothing types. Data points depict only those segments with 5 or more participants. From Armstrong LE, Johnson EC, Casa DJ, et al. The american football uniform: Uncompensable heat stress and hyperthermic exhaustion. J Athl Train. 2010;45(2):117-127.

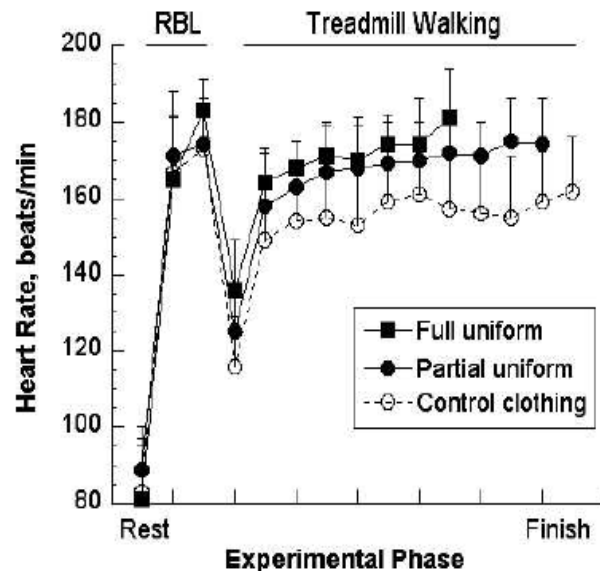


Figure 9- Heart rate responses (mean \pm SD) during repetitive box lifting (RBL), recovery, and treadmill exercise while wearing 3 different clothing types (N=10). Statistically different PART and FULL compared to CON ($p = 0.04$) at the 40th minute of exercise. Data points depict only those segments with 5 or more participants. From Armstrong LE, Johnson EC, Casa DJ, et al. The american football uniform: Uncompensable heat stress and hyperthermic exhaustion. J Athl Train. 2010;45(2):117-127.

III. Performance

A. Hydration

Dehydration reduces the overall water volume in the body,^{44,45} resulting in a reduction in central blood volume and skin blood flow.^{45,46} An athlete in a hypohydrated state may experience an increase in CV strain, increase in T_{RE} rate of rise, decrease in sweat rate due to reduction in skin blood flow, and reduced plasma volume.^{5,9, 18,45,47} When a decrease in blood volume occurs, and the atrial stretch receptors signal the hypothalamus which reduces the sweat rate response. The lack of blood volume sensed by the stretch receptors reduces blood flow to the skin in an attempt to maintain blood pressure. This reduction in skin blood flow minimizes heat transfer to the environment via evaporation and as a result T_{RE} or the rate of heat storage increases.

During exercise in the heat, core body temperature and HR increase by 0.22°C and 3 to 5 b·min⁻¹, respectively, for every additional 1% body mass loss.⁴⁸ In a typical football practice with mild to moderate environmental conditions, football players can easily lose 4-5% of their total body mass.^{47,49} Proper hydration before and during exercise is imperative for maintaining proper thermoregulation.⁶ Often individuals rely on thirst sensation to dictate when to hydrate, but for an exercising individual in hot and humid environment this would be an inadequate method of rehydration. Thirst is not perceived until a loss of approximately 2% of total body mass occurs.⁵⁰ This is relevant because as little as 1-2% body mass loss contributes to an elevated T_{RE} and cardiovascular (CV) strain.⁵¹ In other words, at the point when one realizes they are thirsty, a detrimental effect on performance has likely already occurred. It has long been supported that ingesting fluid 60 minutes before exercise can reduce CV strain and lower core body temperature⁵² and more so that proper hydration helps optimize blood volume and heat loss.

Proper hydration during exercise has shown to: enhance heat dissipation, limit plasma hypertonicity and helps maintain cardiac output.^{6,45} Montain et al.⁴⁵ studied cyclists working at a power output of 62-67% maximal O₂ consumption and tested the effects of 4 varying amounts of fluid replacement (none, small, moderate, or large amounts of fluid). This landmark study concluded that the magnitude of increase in T_{RE} and HR as well as the observed decline in stroke volume were linear in nature in proportion to the amount of dehydration during exercise. It was also found that the large fluid group had a mean of 20-22% increase in forearm blood flow compared to all other treatment groups.⁴⁵

Hydration status directly effects cardiovascular performance, which has a direct and large influence on muscular power.^{7,8,45,46} The studies investigating this relationship have not been in consensus, thus a mixed framework of knowledge has been reported. Some studies have shown that there is a critical level of fluid deficit where changes in anaerobic power are seen.^{7,8} Montain et al. examined fluid replacement at 4 levels (80%, 60%, 40%, and 20% of total sweat loss). All groups exercised in the heat and performed both tests of aerobic and anaerobic performance after receiving the specified fluid replacement.⁸ This investigation concluded that dehydration can adversely influence both aerobic and anaerobic performance with anything less than 40% sweat loss replacement and that aerobic performance declined more than anaerobic (Figure 10).

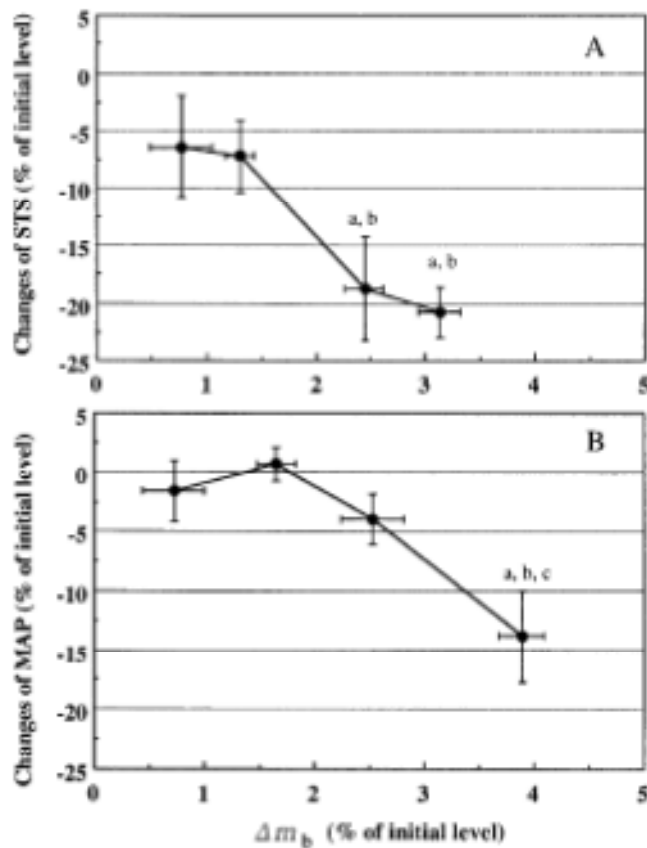


Figure 10- Relationship between changes in step test scores (STS), maximal anaerobic power MAP, and body mass loss during baseball practice in the heat with four conditions of fluid ingestion (FI). Points show the means and SEM bars for subjects. The % change in STS and MAP were calculated from values pre and post practice. Significant differences of MAP or STS ($P < 0.05$) at 80%, 60%, and 40% FI, respectively. From Yoshida T, Takanishi T, Nakai S, Yorimoto A, Morimoto T. The critical level of water deficit causing a decrease in human exercise performance: A practical field study. *Eur J Appl Physiol.* 2002;87(6):529-534.

A more recent study found that a dehydrated state of 2.9% body mass loss decreases the ability to produce upper and lower body anaerobic power.⁷ After a treadmill protocol in a hot and humid environment subjects performed a Wingate test to measure power output. The dehydrated subjects mean power for upper and lower body was significantly decreased (7.17% and 19.20% respectively), as well as peak upper and lower body power (14.48% and 18.36% respectively). Using results from studies like these, the optimal rate of fluid replacement is one that approximates sweat rate.⁴⁵ This theory has not gone without contest. Research has stated that athletes cannot tolerate the amount of fluid necessary to approximate body mass loss. Football players can lose anywhere from 4-5% of their total body mass in one practice, so the gastrointestinal discomfort of a large quantity of fluid in a short period of time outweighs the physiologic benefits. Instead, to limit physiologic decrements in performance,

approximately 500 mL of water should be ingested and if environmental conditions cause an increase in sweat rate then hydration should subsequently be increased.³¹ By doing so it not only promotes thermoregulation, but also allows for proper cellular function leading to adequate release and utilization of energy stores.

B. Energy Systems Utilized during Football Activity

American Football is comprised of short bursts of maximal-intensity activity (2-5 seconds in duration) followed by a recovery period lasting up to 25 seconds. This exercise to rest ratio would appear to pose a significant stress to the anaerobic energy system. The amount of recovery between plays does not appear to be sufficient to allow complete restoration of intramuscular phosphocreatine.⁵³ It was explained in the study by Pincivero et al. that the combative nature of this sport could also cause muscle tissue damage and neural disruption, potentially contributing to further performance decrements as the game proceeds.⁵³

C. Football Specific Skills

Physical performance tests are conducted at the amateur and professional sporting levels to evaluate players for selection and to monitor training adaptation.⁵⁴ Standardized physical tests are performed to obtain normative values for various position groups. A well known battery of tests implemented by the NFL to rate potential rookie football athletes is the NFL Combine. For the purpose of this study power, balance, agility and speed are outlined below to gain an understanding to how they relate directly to football activities.

The testing battery utilized by the NFL Combine is sport specific and executed on the field as opposed to a laboratory setting. Each athlete may complete a 36.6-m sprint, vertical jump, 18.3-m shuttle, three-cone drill and bench press. These exercises collectively represent the player's abilities on

the football field, and their performance of some or all may affect their draft status.⁵⁵ In conjunction with typical tasks executed in practice the combine performance battery allows us to understand the important elements of football performance, which are speed, power and agility.

When laboratory studies choose to implement a methodology that involves sport specific activities a typical difficulty is using tasks offering high carry over to on field performance. A counter movement vertical jump (CMVJ) allows for maximum power output, eliciting a maximal exertion of the bodies systems.⁵⁶ The CMVJ can easily be executed in a lab and closely correlates to the standing vertical jump used in the combine. Using a QuickBoard to measure reaction time and foot speed is quantifying an athlete's agility status, which can allow for extrapolation of one's ability to change direction on the field.⁵⁷ In a laboratory setting where space is limited running will usually be confined to a treadmill, so to measure peak speed a non-motorized treadmill can be used. By measuring the speed at which the belt spins it can give an accurate estimate to the ground an athlete can cover within a specified duration of time.⁵⁸ At the foundation of all of these movements is an athlete's balance and proprioceptive qualities. A valid and easily implemented test for balance is the balance error scoring system.⁵⁹

We now understand the heat stress and subsequent performance decrements with football athletes competing in the heat. Also, we see the role of hydration has on performance and physiological function. External cooling modalities are another option for assisting the body's thermodynamic system while exercising in the heat. They are typically scrutinized based on their efficiency (cooling rate) whereas the more efficient they are, leads to an attenuation in the rise of T_{RE} .

IV. Methods for Heat Removal

A. Cooling Modalities and Cooling Rates

Numerous research studies have explored different cooling modalities or applications of cold to the body.^{10,60} During an athletic event it is common for an athlete's body temperature to reach 103°F (39.4°C)^{5,14} and rest periods can be relatively short. In order for the cooling modality applied to be beneficial it must have an adequate cooling rate. The cooling rate of a modality refers to its ability to remove heat from the body over a unit of time. For example, if athlete 1 uses a cooling modality that provides an adequate cooling rate (i.e. 0.10°C·min⁻¹)⁶¹ but athlete 2 receives a substandard cooling modality providing a cooling rate of just 0.03°C·min⁻¹, after 5 minutes athlete 1 will have a reduction of 0.5°C whereas athlete 2 will only have a 0.12°C reduction. Athlete 1 will have a physiological advantage over athlete 2. To better understand we must recognize that in an athletic setting the rest period is predetermined, consistent, and typically brief so a convenient cooling modality with a cooling rate that has the ability to remove the largest amount of heat is critical. Physiological and performance benefits depend on the effectiveness and efficiency of the cooling treatment. Outlined below is a brief description and effectiveness of widely used cooling modalities.

Cold water immersion (CWI) has been shown through many studies to be the "gold standard" for treating an athlete with EHS.⁶¹ The goal of this treatment method is to fully submerge an athlete into a tub of water. With a high percentage of body surface area being treated at once, combined with the high capacity for thermal conductivity of water, this translates into a much greater potential for heat transfer.⁶¹ In the study by Casa et al.⁶¹, they refuted the claims that CWI may cause individuals to heat up (or at least not cool down) due to a peripheral vasoconstriction and shivering. This brief and minimal protective mechanism coined the term "Currie Response" does not occur in individuals with EHS. CWI cooling rates have been studied extensively, and although not all studies are truly comparable because

of methodological differences, it can provide a framework for its effectiveness. Cooling rates range from 0.15 to 0.35 °C min⁻¹ (see Figure 11) depending on the temperature of the water used in the study.

Logistical reasons and time constraints sometimes discourages the use of CWI to cool athletes without EHS. It is important to understand that all cooling modalities being discussed below are not being suggested for the treatment of EHS. They merely are designed, and have been tested for effectiveness of attenuating the rise of core body temperature in a heat stressed individual. It has been postulated that athletes, whether during practice or game situations, could utilize modalities that offer a logistical possibility of maintaining a lower T_{RE}. Other cooling modalities have been marketed to be easy to use and more portable allowing for ease of implementation outside or in a hurry. These devices include: 1) cooling collars 2) Cooling jackets 3) Cooling vests 4) hand cooling refrigerant packs each of which utilize multiple reusable chemical ice packs constructed together in a manner that they can be worn by an athlete. The goal of these devices is to cover as much surface area with the ice packs and targeting heat transfer systems (i.e. arteries, torso). The research on the effectiveness of these cooling modalities is

inconclusive.^{49,62-70}

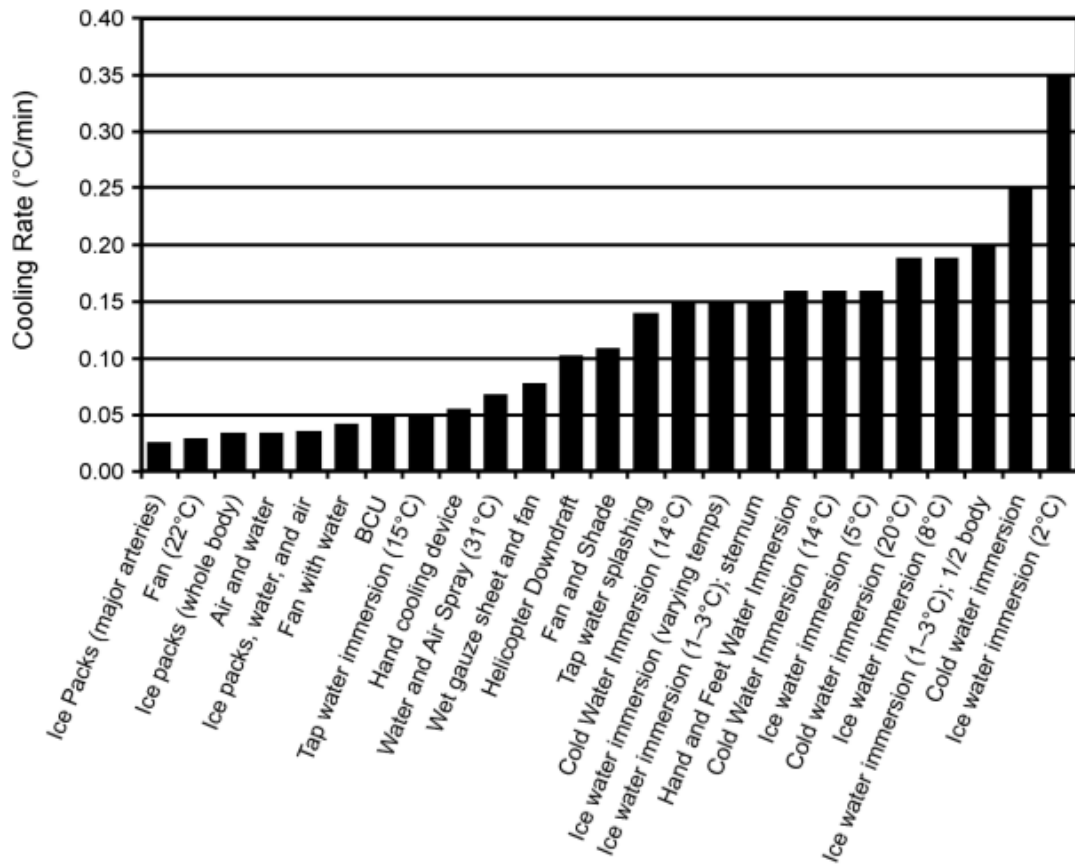


Figure 11- Mean cooling rates from case reports and reviewed articles. Mean cooling rates defined as unacceptable are $< 0.078^{\circ}\text{C}\cdot\text{min}^{-1}$, acceptable are 0.078°C to $0.154^{\circ}\text{C}\cdot\text{min}^{-1}$, and ideal are $\geq 0.155^{\circ}\text{C}\cdot\text{min}^{-1}$.

Some of the discrepancies are due to the many different methodological designs. Overall, most current research has shown that cooling methods other than CWI are only effective at mitigating the rise of T_{RE} rather than for the treatment of EHS. The main rationale behind this is based on the unacceptable cooling rates required to remove heat with a 30 minutes cooling treatment (Figure 11 and Figure 12).⁷¹ This is mentioned not to down play the proposed benefits of cooling garments, but to outline the current research available on these modalities. It can be argued that there are varying effects based on exercise intensity, length of treatment, or environment in which it is applied. These “unacceptable” or reduced cooling methods for EHS can still be extremely effective in the prevention of any hyperthermic athlete and potential EHI.

DeMartini et al.¹⁰ performed a field study examining the effectiveness of multiple cooling methods on core body temperature, HR, and perceptual measures. The exercise sessions were in warm conditions (WBGT mean= 26.64°C) and the intensity was self-paced (games of soccer, ultimate Frisbee, and field games). The various cooling modalities were applied after 45-60 minute exercise bouts. The results showed that only a few of the cooling modalities resulted a rapid drop in core body temperature than the control trial. The control group had a 1.50° F drop in core body temperature in approximately 17 minutes compared to the same 1.50° F drop using three other methods CWI, Nike Ice Vest™, and ice bucket cooling of hands and feet which were 14.0, 16.0, and 12.0 minutes respectively. The remainder of the cooling modalities ice towels, GameReady™ Vest, Rehab Hood™, and Emergency Cold Contaminant System™ (ECCS), Port-a- cool™ fan, and sitting in the shade all had decreased cooling rates compared to the control group (Figure 12). Some limitations of this study were low core body temperatures prior to cooling (mean 38.73°C) and low environmental temperatures (26.64°C). The fact that exercise intensities were not controlled may not have allowed the core body temperature to sufficiently increase. This study was the first to investigate most of these cooling modalities within this methodology. This is important to form a framework of understanding for potential tools that can be

utilized to limit the amount of time individuals are subjected to physiological stressors of hyperthermia, mainly increase in T_{RE} and elevated HR.¹⁰

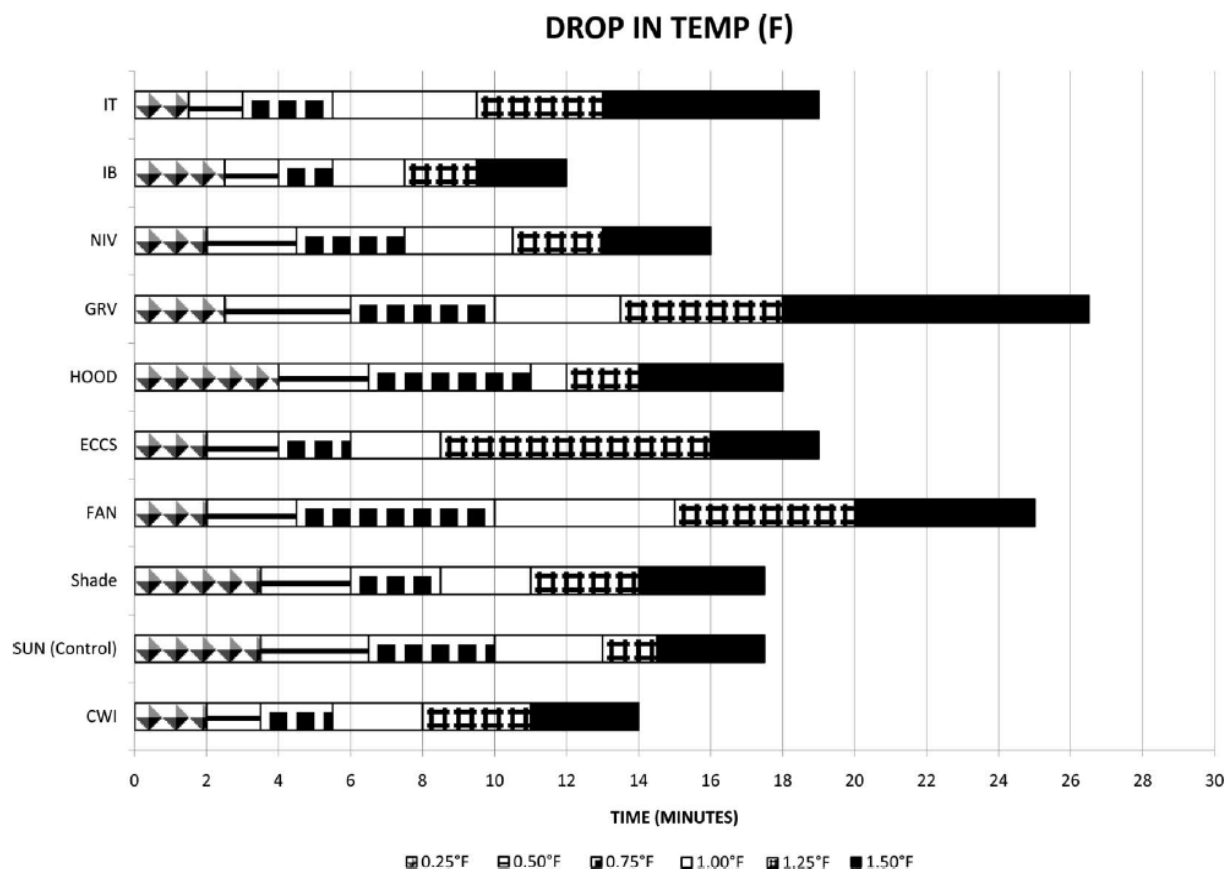


Figure 12- Drops in Rectal temperature in 0.25°F increments over time for each modality. 0-minute time point= immediately before cooling, 10-minute time point= end of cooling phase, and 30-minute time point = end of monitoring phase. *From DeMartini JK, Ranalli GF, Casa DJ, et al. Comparison of body cooling methods on physiological and perceptual measures of mildly hyperthermic athletes. J Strength Cond Res. 2011;25(8):2065-2074.*

Cooling modalities carry with them many benefits, but the limitations of these modalities must not go without notice. Ice vests for example, have been manufactured to cover the torso with cold packs that sit directly on the skin and research has indicated the ice packs in the cooling jacket cool the body effectively. The main heat loss mechanism is through continuous conduction of heat from the skin surface to the ice pack and furthermore vests have been considered to aid the thermoregulatory system and exercise performance positively.⁷² On the contrary, cooling vests have been shown to inhibit

evaporative heat loss from the torso due to the garments inherent qualities. When this was examined further, although the evaporative sweat loss was diminished, the ice pack coverage over a large skin surface area removed heat from the core effectively.⁷² The conflicted findings of insignificant^{49,68,71,73} and significant cooling rates^{72,74,75,76,77} when investigating the ice vests is thought to be due in part by the disruption of evaporative cooling. If exercise intensity or environmental conditions (temperature, humidity and equipment) become too great, then the effectiveness of the device decreases because of the potential that the vest has to remove heat compared to the body's production. It is important to note that the methodology for studies that showed improvement on reduction in T_{RE} initiated pre-cooling prior to the thermal strain on the body. In these cases it increases the heat sink, or lowers the initial core temperature below the normal resting point and thus when T_{RE} increases via exercise, a greater potential for heat storage and increased time to peak T_{RE} is established.

Both the Rehab Hood™ and the Emergency Cold Containment System™ (ECCS) are designed with micro beads throughout the lining that are activated when doused with water. The units are kept in a refrigerator or cooler and maintain a temperature of 7-16°C (45-60°F). The Rehab hood covers the forehead to the base of the posterior neck and spans the lateral head and over the ears. The ECCS™ unit is placed on the upper body, housing the head inside and allows the arms to be removed for vital signs and intravenous application. DeMartini et al.¹⁰ were the first to investigate the cooling rate for the ECCS™ and the first to use the Rehab Hood™ in a hyperthermic athletic population. Although more investigation is needed to gain better insight, this study showed that T_{RE} and HR were not significantly lower with the use of the Rehab Hood™ at any time point (Figure 13 and Figure 14). It was concluded that this was due to the small surface area the garment covered and that the body was unable to dissipate heat effectively through the head alone.¹ The ECCS™ significantly lowered T_{RE} ($p = 0.002$) compared to SUN group $-0.68 \pm 0.44^{\circ}\text{C}$ (1.22°F) vs. $-0.42 \pm 0.15^{\circ}\text{C}$ (-0.75°F) respectively (Figure 12). ECCS HR after 10 minutes of cooling was significantly different than SUN ($p < 0.006$) $87 \pm 14 \text{ b} \cdot \text{min}^{-1}$ and $101 \pm$

15 b·min⁻¹ respectively (Figure 14). With minimal data to compare to, it is difficult to speculate what the physiological mechanism for the effectiveness of the ECCS however, the HR was speculated to be different due to body posture during the 30 min treatment.¹⁰ The SUN group was in a seated position while the ECCS group was in a supine position and may have had an effect. It was speculated that this position may have aided in venous return, leading to a quicker restoration of central blood volume after intense exercise. When central blood volume is restored HR will begin its decline sooner since CV strain is reduced.

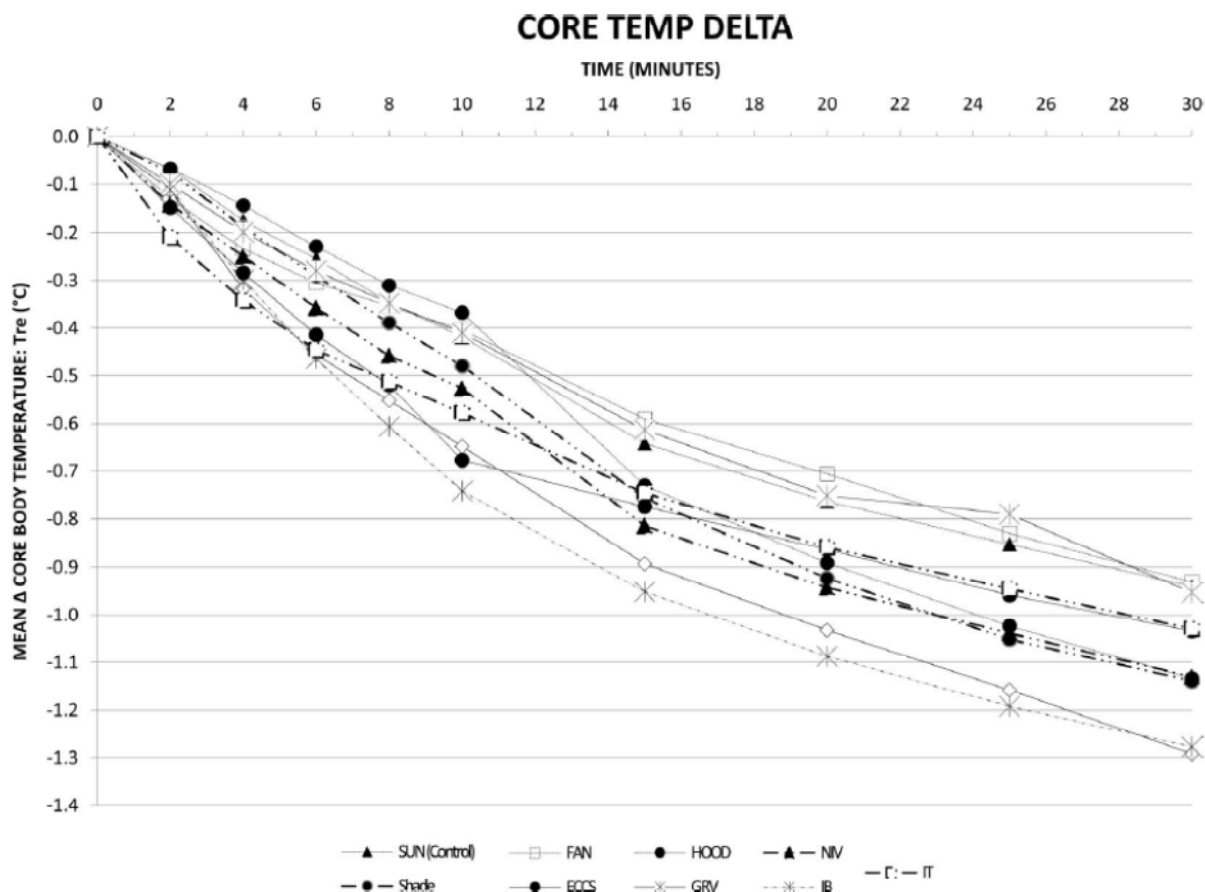


Figure 13- Core body temperature over time for modalities. 0-minute time point= immediately before cooling, 10-minute time point= end of cooling phase, and 30-minute time point = end of monitoring phase. Significance at the 10-minute time point for cold water immersion (CWI), emergency cold containment system (ECCS), and ice buckets (IBs). From 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.

Ice towels have been used in many previous studies; however it is usually used as a means to treat EHS. The results from DeMartini et al.¹⁰ showed that there was not a significant difference ($p=0.042$) in cooling after exercise when compared to the SUN group, $-0.58 \pm 0.57^\circ\text{C}$ (1.04°F) and $-0.42 \pm 0.15^\circ\text{C}$ (-0.75°F) respectively. It was believed that the water being used did not remain at an adequate temperature when towels were rotated. It should also be mentioned that this modality is difficult to use in a practice or game situation because in some instances equipment or clothing may need to be removed.¹⁰

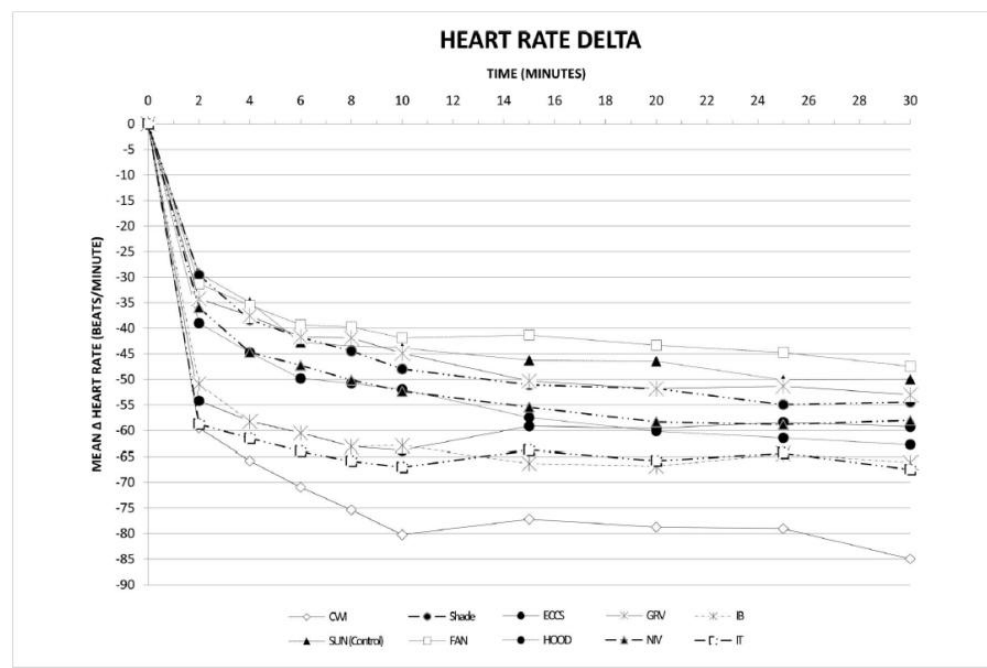


Figure 14- Heart rate changes over time for modalities. 0-minute time point= immediately before cooling, 10-minute time point= end of cooling phase, and 30-minute time point = end of monitoring phase. Significance at the 10-minute time point for cold water immersion (CWI), emergency cold containment system (ECCS), ice towels (IT). From 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.

B. Mechanisms of Extremity Cooling

The cardiovascular system adapts to thermal stress by redistributing blood flow to vital body systems. This redistribution of blood to the periphery is crucial to thermoregulation. Blood is diverted to

the periphery and specifically to highly specialized circulatory vessels known as arteriovenous anastomoses or AVAs in the glabrous skin regions. Rowell et al.⁷⁸ further supported this theory that blood flow is increased to the periphery when they examined changes in blood flow to various organs during thermal stress (Figure 15). Their results demonstrated that in resting subjects extreme thermal stress caused cardiac output to increase by 6-7 L/min, blood flow to the visceral organs to decrease, no change in skeletal muscle blood flow, mean arterial pressure to decrease (despite the doubling of cardiac output), and a six-fold increase in blood flow through the forearm. It was concluded that the increased cardiac output was pumped through the skin. This study was further supported by Montain et al.⁴⁵ when they found a 20-22% increase in forearm blood flow during a study on graded dehydration and exercise performance supporting the theory that blood flow is redistributed to the periphery. In order to examine how the delivery of blood flow occurs, Grahn et al.⁷⁹ described the glabrous skin which are defined as non-insulated skin regions on the palms of the hands, the soles of the feet, the ears, and the face.^{80,81} The blood flow to the skin passes through and is regulated by heat-transfer units in the glabrous skin which can withstand large influx in blood to the area and acts as a "gate keeper" to the outside environment. It can be noticed in Figure 16 in an infrared image of a female runner that the palms of the hands and the face are much warmer than the rest of the body surface which supports this theory.⁷⁹

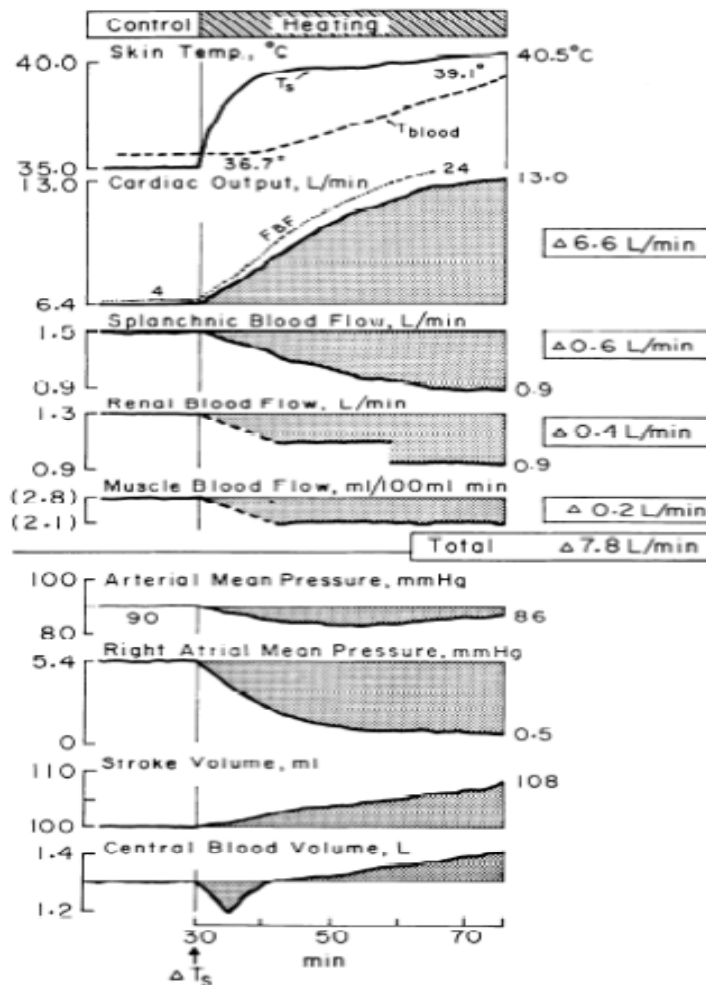


Figure 15- Average circulatory changes during passive heating 30-53 minutes. Only initial and final values are shown for each cardiovascular variable: skin temp., cardiac output, splanchnic blood flow, renal blood flow, muscle blood flow, arterial mean pressure, right atrial mean pressure, stroke volume and central blood volume. Changes in CO, SBF, RBF and MBF are shown on the right side of figures (total = 7.8 liters/min). From Rowell LB. *Human cardiovascular adjustments to exercise and thermal stress. Physiol Rev.* 1974;54(1):75-159.



Figure 16- Infrared image of an exercising individual. Note the lighter yellow and orange colors indicate an increase in heat in the area. The palm of the hands and face (glabrous skin surfaces) have the most heat present. *From Grahn DA, Heller HC. The physiology of mammalian temperature homeostasis. Int Trauma Anesthesia Critical Care Soc. 2004:52-61.*

The heat transfer units within glabrous skin surfaces are made up of venous plexuses (dense network of thick walled, large diameter venules) and arteriovenous anastomoses or AVA's which are vascular communications between small arteries and the venous plexuses. The AVA's directly control the blood flow through the venous plexuses, and since the venous plexuses are the only portion of the circulatory system in contact with the external environment, constriction utilizing AVA's isolates the body from the environment. Conversely, dilation of the AVA's promotes the exchange of heat between the body's core and the environment.⁷⁹

In recent research by Sangiorgi et al.⁸² and Manelli et al.⁸³ they visually identified the previously mentioned structures and the specified design of the hypodermic layer of the hand. Both studies utilized a supranumerary thumb injected with casting material through the arterial system. The thumb was dissected to obtain visualization of the vascular structures on the dorsal and palmar portions of the

digit. One study utilized a scanning electron microscopy analysis (SEM) to obtain 3D images of the vascular structures.⁸³ With these images the structure and function of AVA's and glomerular- shaped vessels was further analyzed and revealed that the hypodermal layer is densely packed with sweat glands, arteriovenous anastomoses, and glomerular-shaped vessels.⁸³ These vessels are relatively large in diameter compared to capillaries and are aligned in parallel with each other allowing for ease of movement and flow.^{82,83} The purpose of these highly specified structures are to allow for a low-resistance pathway⁸² and accommodate an abundance of blood flow during vasodilation of peripheral vascular structures. Glabrous skin has been identified as a highly specified tissue and critical for heat exchange with the surrounding environment. These studies are crucial to understanding the role the hands, feet, and face play in the thermodynamic system.

To further investigate the functionality and effectiveness of glabrous skin, the re-warming of hypothermic subjects under anesthesia was investigated.⁸⁴ In this study the control group received warming to a single forearm and hand, while the treatment group received the same warming, but with subatmospheric pressure applied to the hand and forearm. They concluded that utilizing circulating blood to transfer heat between the glabrous skin surface and the body core is a more efficient method for transferring heat than is conduction through peripheral tissues (Placing items on the skin).⁸⁴ Furthermore, results showed that the transfer of heat between glabrous skin and the body's core is six times greater when subatmospheric pressure is applied to the limb.⁸⁴ Based on these results, it can be concluded that the transfer of heat between glabrous skin and an outside source is directly related to the amount of blood flow through the skin and the temperature gradient between the blood and external environment. Figure 17 below depicts the transfer of heat and the structures involved with external cooling. One particular structure, the rete venosum, receives a large quantity of warm blood from the central blood volume. With the application of cold, a temperature gradient forms between the blood and an external cooling source, allowing for transfer of heat from the rete venosum, through the

dermal layers and to the cold source.⁷⁹ When vascular structures in the glabrous skin are vasodilated blood flow and heat exchange increase.^{82-84,79} If an external source applied to the area is cooler than the blood, the temperature of the blood will decrease via conduction. In theory this transfer is logical and has the potential to remove a large amount of heat from the body, however the theory behind the transfer mechanism and its influence on the core body temperature is not well understood.

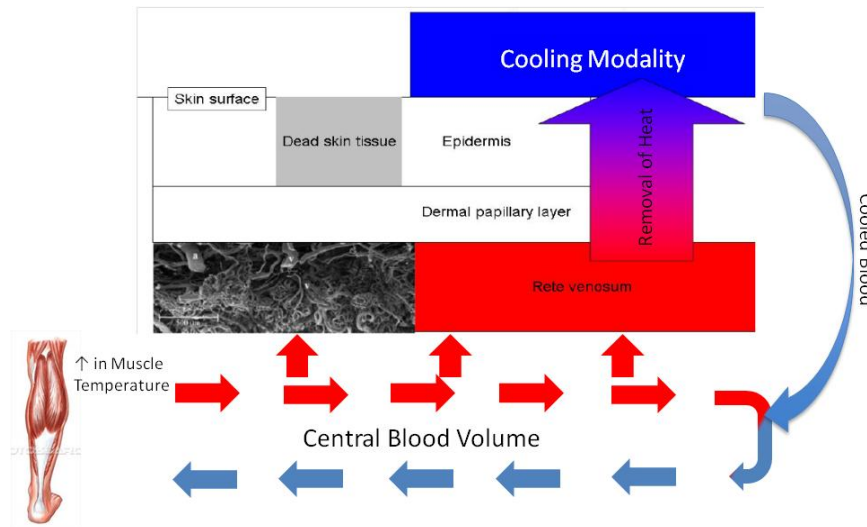


Figure 17- Adapted depiction of blood flow from active muscles into the central blood volume. Heat leaves the central blood (Red arrows) into the rete venosum within the skin. Heat moving through the dermal layers as the cooling modality is applied to the surface of the skin causing heat removal via conduction. *From Grahn DA, Heller HC. The physiology of mammalian temperature homeostasis. Int Trauma Anesthesia Critical Care Soc. 2004:52-61.*

Two potential theories have emerged that may explain the mechanism behind the cooling of the body. One theory is that the cooled blood mixes with the circulating blood in the heart resulting in an immediate cooling effect of the body's core. The other theory describes the effect the cooled blood has on receptors located in blood vessels, the brain, muscle and viscera.^{85, 86} In response to a reduction in temperature these receptors send afferent sensory information to the supraspinal pathways and into the hypothalamus that hyperthermia is reduced. This sensory information will elicit an inhibitory response to cease or reduce sweating. This false inhibition may then place the individual at a

disadvantage because it is well documented that sweating is the primary mechanism for heat dissipation.⁸⁶

It has been estimated that blood flow into the venous plexuses can range from nearly zero flow during cold stress to as much as 60% of the total cardiac output during heat stress.⁷⁹ As blood is shunted to the face, feet, and hands in an attempt to cool, the blood flow to other regions of the body decreases. More importantly to the exercising individual, perfusion of blood to active skeletal muscle will decrease, causing a detriment to muscle output. To mitigate this negative response, studies have investigated techniques to attenuate the rise in core body temperature hoping to decrease the negative effects on performance during activity in a hot environment.^{87-91, 92-97}

Applying cold to the surfaces of the hand and feet have been investigated in depth and have shown that it is an efficient method to reduce T_{RE} .^{10,98-102, 103, 104} Typically this is done utilizing ice baths (IB) to submerge the hands and upper extremities or the feet and lower extremities. Although often studied as a treatment tool for EHI^{103, 98,101,102} there are studies that have investigated its effect on T_{RE} either as a pre-cooling modality or post exercise.^{10,60,99,100,104} These studies form the back bone of hand cooling devices recently put on the market such as hand cooling gel packs and self-contained hand cooling systems however contrasting research in the area of peripheral cooling has emerged.

One study examined 6 different cooling modalities (4 active, 2 passive) in a climate controlled room while IV saline was administered in fire fighters after working in hot environment for 50 minutes.¹⁰⁵ The 20 minute cooling sessions for each of the 6 groups yielded no change on HR or core body temperature. It was postulated that the observed diminished effect of the cooling treatments was due to the moderate temperatures (35°C,50% RH) rather than a hot environment.¹⁰⁵ In contrast, Selkirk et al.¹⁰⁶ found that active cooling blunted the rise in T_{RE} and extended work time when compared to passive cooling.

Another study,¹⁰⁷ applied a cooling device to the foot (also glabrous skin) and measured T_{RE} via tympanic membrane in two groups. Both spinal cord injured individuals and able-bodied individuals were instructed to perform an upper body bike protocol and a significant difference in T_{RE} during recovery was seen in the cooling group compared to control group.¹⁰⁷

C. Hand Cooling

Over 50 years ago it was demonstrated that heat could effectively be extracted from the body core through the hands and feet.^{108,109} This demonstration ultimately leads to the discovery of the glabrous skin and the thermoregulatory mechanism behind this method of heat exchange. Furthermore, it has also been demonstrated that exposure to subatmospheric pressure increases blood flow through the fingers and toes.^{110,111} When these two principles are combined, it supports the theory behind the application of subatmospheric pressure and cold thermal load to the hand. This application would, in theory, provide direct transfer of cool blood to the central vasculature of the body.⁷⁹ This premise formed the basis behind the CoreControl™ device.

The CoreControl™ is a hand-cooling device in which a hand is inserted into a chamber with equipped with an airtight seal that forms around the wrist. The hand rests on a surface that is cooled by temperature controlled water at 16°C. The chamber is equipped with a vacuum source and pressure sensors to create a slight sub-atmospheric pressure (~40mmHg). By creating a negative, sub-atmospheric pressure, excess blood is drawn into the fingers.¹¹² This allows for increased heat dissipation through the palmar surface of the hand via vasodilation of the subcutaneous veins which are supplied a great amount of blood flow.^{89,79,90,91} This large amount of warm blood exposed to the cold surface of the unit cools the blood as it circulates through the hand. The cooled blood is then returned back to the central vasculature via venous return which then circulates throughout the body and to the

exercising muscles where heat is again transferred from the metabolic heat produced by the active muscle and back to the periphery and hand.

It has been hypothesized and discussed for many years now, that through local application of subatmospheric pressure to expand the retia venosum (palmar surface part of the glabrous skin) and applying a heat sink, it is possible to manipulate core body temperature.^{84,88,89,91,107} A specific example was from the work of Hsu et al.⁸⁹ who found that T_{RE} rise was attenuated and mean oxygen consumption and blood lactate decreased with the use of a hand cooling device (Figure 18). A decrease in oxygen consumption indicates a more efficient bout of exercise and leads us to believe that CV strain was decreased in the IB treatment group. They also found that performance increased, reporting a 6% difference in time to complete a 30- km bike test in the cooling group compared to control (see Figure 19).

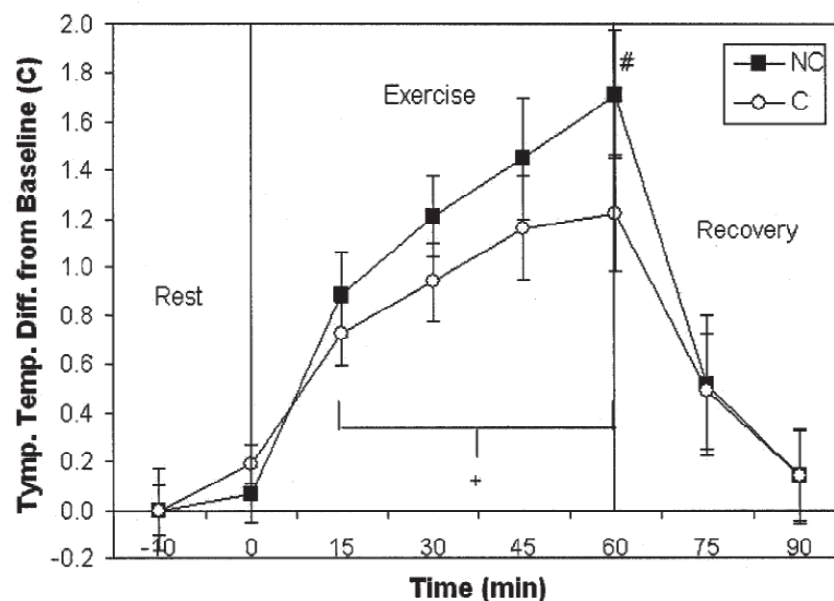


Figure 18- Tympanic temperature (T_{Ty}) difference from baseline during rest, exercise, and recovery. # Peak increase in NC significantly different from C ($p < 0.01$), + Significantly different from rest ($p < 0.05$). NC= noncooled, C= cooled. From Hsu AR, Hagobian TA, Jacobs KA, Attallah H, Friedlander AL. Effects of heat removal through the hand on metabolism and performance during cycling exercise in the heat. *Can J Appl Physiol.* 2005;30(1):87-104.

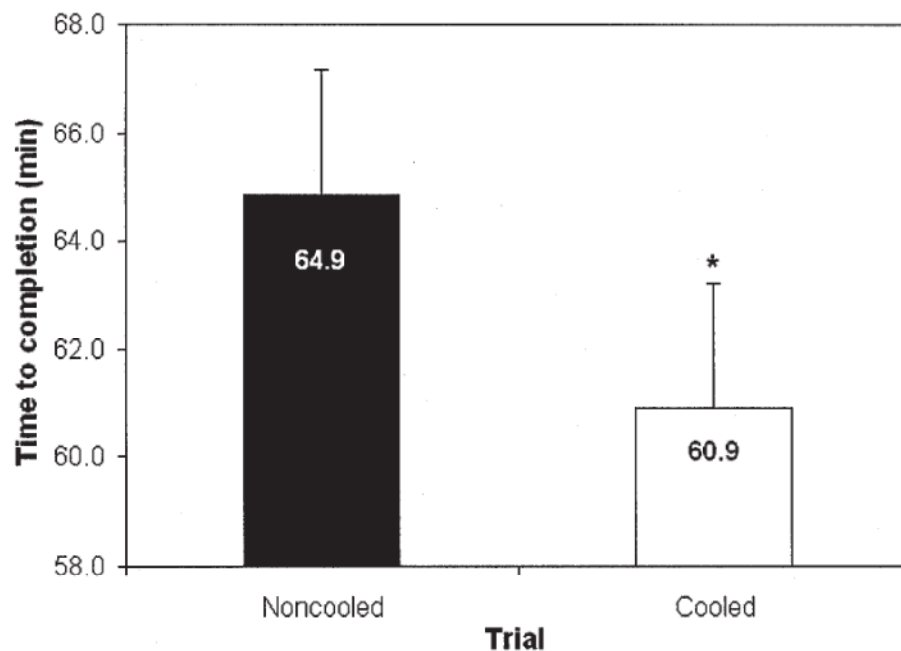


Figure 19- Time to completion of 30-km cycling trial (mean \pm SEM). *C_T significantly different from NC_T (p < 0.01). NC_T= non-cooled; C_T= cooled. From Hsu AR, Hagobian TA, Jacobs KA, Attallah H, Friedlander AL. Effects of heat removal through the hand on metabolism and performance during cycling exercise in the heat. *Can J Appl Physiol.* 2005;30(1):87-104.

Another study investigated the difference in the hand cooling device with and without subatmospheric pressure as well as the difference of cooling on 5 specific combinations using 4 glabrous skin surfaces (Ears, Face, Feet and Hands).⁹¹ Subjects received one of the cooling modalities during a recovery period of 60 minutes after exercising for approximately 45 minutes wearing military battle dress. The battle dress impedes the body's thermodynamic system due to a reduction in evaporative heat loss. Cooling two hands with subatmospheric pressure showed a significant difference over the one hand cooling group with subatmospheric pressure (mean of 1.3°C·60min⁻¹ and 1.0°C·60min⁻¹ respectively). Interestingly this data was presented ·60min⁻¹ which differs from most cooling literature which examines cooling rates ·1min⁻¹. When put into perspective this is a cooling rate of 0.021·1min⁻¹ and 0.016·1min⁻¹. When comparing the effects of subatmospheric pressure in combination with hand

cooling results showed a significant difference between one hand cooling with subatmospheric pressure and no treatment groups only (mean $1.0^{\circ}\text{C}\cdot 60\text{min}^{-1}$ and $0.4^{\circ}\text{C}\cdot 60\text{min}^{-1}$ respectively), one hand without subatmospheric pressure was $0.8^{\circ}\text{C}\cdot 60\text{min}^{-1}$. It was found that the treatment of multiple surfaces created an additive effect in cooling rates. Cooling rates for face, two hands and two feet groups independently and the combination group of face, feet and hands were $1.0^{\circ}\text{C}\cdot 60\text{min}^{-1}$, $1.3^{\circ}\text{C}\cdot 60\text{min}^{-1}$, $1.3^{\circ}\text{C}\cdot 60\text{min}^{-1}$, and $1.6^{\circ}\text{C}\cdot 60\text{min}^{-1}$ respectively. The differences between each of these cooling groups and the control group were significant ($p<0.05$). When investigating the effects of each cooling method on HR attenuation, it was determined that the face, feet, and hands group ($103\text{ b}\cdot\text{min}^{-1}$) was the only significantly different post recovery HR measure compared to one hand, two hand, feet only, face only cooling and the control group ($121\text{ b}\cdot\text{min}^{-1}$, $112\text{ b}\cdot\text{min}^{-1}$, $114\text{ b}\cdot\text{min}^{-1}$, $117\text{ b}\cdot\text{min}^{-1}$ respectively).

D. Opportunities for Cooling In Football

American football competitions can pose a logistical challenge when examining the opportunities to implementing the use of cooling modalities. An American football game consists of four 15 minute quarters with an approximate 20 minute halftime after the 2nd quarter. Traditionally cooling has been commenced once in the locker room during halftime⁷⁴, however one application of a cooling modality within 1 hour of play is less effective⁷⁴ and the logistical concerns of allowing 50-60 players use a cooling modality within a 20 minute time frame is difficult.

A traditional method of cooling during play of a football game is ice towels. This is the use of cold-water soaked towels placed over the head and neck.¹⁰ This cooling modality will be discussed in detail in a section to follow, and although easier to implement during play it is important to note that the effectiveness of this modality depends on certain variables (temperature of water, time of application).¹⁰

V. Gaps in the Literature

The current literature on body cooling collectively agrees that pre-cooling treatments will increase the body's heat sink while exercising in uncompensable heat stress.^{39,49,60,62-69,72, 73,74,75,76,77,98-101, 103,104,105-107,113,,} Various studies have been conducted examining other cooling modalities (Demartini et al) and recently cooling vests and cooling of the periphery have become an area of interest for inventors in an attempt to provide easy, safe and convenient ways to prevent the storage of heat within the body. More specifically, peripheral cooling of the hand has begun to gain momentum in recent years with teams such as the football team at Stamford as well as the San Francisco 49ers. Studies examining localized hand cooling modalities have been performed in clinical patients with multiple sclerosis and laborers such as firefighters and even in individuals wearing chemical protective clothing however, data is lacking specifically for individuals in American Football Uniforms (Table 1). This data is important to understand the efficacy of these hand cooling modalities in sport. Football specifically has the potential to benefit most from data examining the influence of hand cooling on core body temperature due to the unique heat stress inherent to the players and the protective equipment worn. Furthermore, no research exists examining the influence of intermittent hand cooling on physiological measures of core body temperature, cardiovascular stress, and performance measures.

It is well documented that uncompensable heat stress causes a decrease in performance and a reduction in the time to exhaustion compared to compensable conditions. Football athletes are a different population defined by the degree of heat stress encountered due to the protective equipment worn, the high intensity of the activity, and the large body mass of its players. This specific niche provides a good place to begin testing the effectiveness of hand cooling modalities. It is unknown what avenues this modality can be used and hopefully it will become more clear as the foundation of data from solid methodological studies form. We do not fully understand all of the uses for hand cooling

currently and it is unknown what occupations, athletic teams, and exercising individuals could benefit from hand cooling. In order to tailor a cooling modality to the needs of specific groups of people we must understand treatment parameters and performance benefits, see Table 1 for examples. A majority of hand cooling studies have selected long treatment times that do not reflect practical application for athletics specifically (Table 1).^{46,88,91,112, 92,93,95,96} Also, there has yet to be a hand cooling study that measures performance specific to an athletic event. Most hand cooling studies have investigated effects on T_{RE} in relation to exercise duration^{88,91-97,112} with only a few have measuring variables such as strength, power, and work.^{87,89,90} To better understand how hand cooling modalities effect physiological function there is a need for investigations to determine the effect on performance measures when the rise in T_{RE} is attenuated.

Table 1- This table provides a synopsis of the current literature on the topic of hand cooling.

Author	n=	Exercise Type	Equipment/Clothing worn	Environmental Temperature and % RH	When cooled ?	Cooling modality	Cooling Duration	Independent Variable	Performance Results
Kwon et al. (76)	16	Pull-up or BP	Not mentioned	Not mentioned	After sets 2,3,and 4	RTX	2.5 minutes	BP volume and T es	Improved
Amorim et al. (77)	12	Treadmill walking		42°C /30% RH	Between bouts	RTX WB WPV	approx 40 min.	HR and Exercise duration	No Significant difference No Significant difference Improved
Kuennen et al. (75)	10	Treadmill walking	Chemical protective suit; neoprene gloves	42.2°C /36.5% RH	Post Exercise	PC RTX	50 min.	T es and T skin T es and T skin	Improved
Grahn et al.(50)	17	Treadmill Walking	Heavily insulative clothing	41.5°C /20-30% RH	Post Exercise	one Hand two hands two feet FFH	60 min.	T es T es T es T es	Improved Improved Improved Improved: Additive effect with more surfaces cooled
Zhang et al. (78)	8	Treadmill walking and Bicep Curls	Firefighter gear/ SCBA	33.7°C /40-45% RH	Post Exercise	RTX	40 min.	T re	Improved:144% cooling capacity over passive cooling
Grahn et al. (74)	10	Treadmill Walking	Exercise clothing	23.0°C /10-25% RH	Exercise	RTX	Varied	Exercise duration	Improved: Increase in exercise time (33%)
Grahn et al. (49)	13 Condition #1= 5 Condition #2= 8	Treadmill Walking and Cycle Ergometer	Exercise clothing; Rain pant/Jacket and cotton hooded sweat suits	34.0°C /30-50% RH	Exercise and recovery; Recovery only	RTX	Varied	T es T es	Improved: Decreased rise of T es Improved: Increased rate of decline during recovery
Walker et al. (48)	10	NMT Intervals	Exercise clothing	23.0°C /30-50% RH	Active Recovery Period	RTX Refrigerant Gel Pack	90s x 8 bouts	Distance and power	No significant differences in power, distance, core temp.
Goosey-Tolfrey et al. (79)	15 WA= 8 AB= 7	Wheelchair ergometer and Cycle ergometer	Exercise clothing	30.8°C /60.6% RH	Between exercise protocol and performance trial	10.0°C WB	10 min.	T ac Time	Improved: Decreased rate of rise in T ac AB and WA; Decreased time of AB and WA performance trials
Hsu et al. (37)	16 Study 1= 8 Study 2= 8	Cycling	Not mentioned	31.9°C /24% RH	During exercise	RTX	Study 1- 60 min Study 2 - Varied	1 hr cycling (fixed workload); 30 km cycling time trial	Improved:Study 1- Increase rise in temperanic temperature/ Increase mean oxygen consumption; Study 2- Decreased time, higher sustained workload
Grahn et al. (2)	67 Protocol #1= 8 Protocol #2= 7 Protocol #3= 10	BP Pull-up and BP BP	Not mentioned	41.5°C/20-35% RH 23°C/20-30% RH 23°C/20-30% RH	Between sets	RTX RTX RTX	3 min. 3 min. 3 min.	Work volume and T es Work Volume Strength	Improved Improved Improved
Grahn et al. (36)	26 Continuous cooling= 8 No pressure Trial= 6	Treadmill Treadmill	Not Mentioned	40.0°C /20-25% RH 40.0°C /20-25% RH	During Exercise	RTX RTX	20-45 min. 10-60 min.	Exercise endurance and T es Exercise endurance and T es	Improved No significant difference
RTX= Rapid Thermal Exchange; WB= Water bath; WPV= Water Perfused Vest; NC= No cooling; PC= Palm Cooling, FFH= Face, Feet , and Hands; SCBA= Self Contained Breathing Apparatus; NMT= Non-motorized Treadmill; WA= wheelchair athletes; AB= Able Bodied; BP= Bench Press									

INTRODUCTION

Many factors influence this heat stress previously discussed, which may increase the susceptibility of a football athlete to heat illness and performance deficits. Football athletes competing in the heat encounter a unique heat stress during activity. The sport of football is often played in the hot and humid summer months during midday. The protective equipment worn during football leads to a unique microenvironment at the skin's surface. The temperature and humidity level increases due to the insulation quality of the equipment, and as this occurs the temperature gradient between the skin and environment decreases.¹⁴ The increase in skin temperature reduces the amount of heat removal from the body through evaporation, convection or conduction. The game of football incorporates high intensity activities of relatively short duration with rest periods that occur often during activity. These rest periods do not allow for T_{RE} to decrease, but rather T_{RE} only plateaus and will continue to rise once activity resumes. Another factor of heat stress in football players is their surface area and muscle mass. As athletes continue to increase muscle mass to achieve performance gains, internal heat production will subsequently increase causing an increase in T_{RE} .³⁷

The ability to maintain internal body temperature increases during exercise in the heat has been shown to be critical for performance.^{5,11} When the amount of heat gain equals the amount of heat loss the body is said to be in a compensable heat stress (CHS) situation, however, when the heat gain exceeds the amount of heat loss, the body is in an uncompensable state. During uncompensable heat stress, the evaporative heat loss required to maintain a steady state exceeds the maximal evaporative capacity of the environment and the body stores heat.

Multiple research studies during UCHS have demonstrated that aerobic fitness, body fatness, and hydration are influential factors in the rate of rise of internal body temperature and tolerance time during heat stress. Interestingly, heat acclimation without the presence of compensable heat stress

(equipment, high heat and humidity) has been the focus for many athletes, war fighters and laborers; however heat acclimation this type of aerobic training has not been shown to aid in increasing tolerance during UCHS. This is opposed to the adaptations that we often see with individuals who are in CHS situations. During CHS, heat acclimation has been shown to increase the cardiovascular and thermal effects in a positive manner increasing exercise tolerance time and allowing the body to reach a state of thermal balance. This same method of heat acclimation prior to UCHS scenarios has been shown to have little influence on tolerance time and the increased sweat rate associated with heat acclimation caused dehydration to occur more quickly which can directly influence tolerance if fluids are not replaced. Many sporting environments are classified as compensable environments even during the summer months, however, when UCHS occurs the heat must be manually removed from the body.^{5,11}

Modalities focusing on heat removal such as vests, towels, fans, misters and even peripheral cooling have been developed to minimize the rate of heat storage. Recently, studies have shown tremendous insight into the use of peripheral hand cooling not only reduce core body temperature but to achieve an ergogenic effect in athletes during short and intense bouts of exercise.^{2,36,37,49,50,76,78,79} The paradigm for this ergogenic effect is centered around core body temperature, and its effects on physiological functions.

Current research has shown that hand cooling modalities are a valid mode for removing heat from the body. However, it is less clear whether the attenuation of T_{RE} leads to an increase in sport performance. Also, we have yet to find out if these performance gains can be accomplished while under uncompensable heat stress. By implementing a study with methodology based on clinical relevance to football athletes, we hope to better understand hand cooling's effect on foundational performance tasks (power, speed, reaction and balance) and the capabilities within a structured treatment duration.

At present, there is little to no data that investigates the effect a hand cooling device has on sport performance.^{2,76,78} This study investigates the performance capabilities of individuals as they execute football specific tasks while in an uncompensable heat stress condition. Previous research has shown that performance decreases during heat stress,^{3, 4,14,22,42,45,46,58}. Furthermore research examining the use of cooling modalities has shown that reducing body temperature during exercise in the heat allows for increased performance¹ and redistribution of blood flow to the exercising muscles rather than to the skin.^{3,129} Therefore, the primary objective of this study was to assess the influence of hand-cooling on rectal temperature (T_{RE}) while wearing football equipment in a hot environment. A secondary aim was to examine the influence of hand cooling on football specific tasks. We hypothesized that intermittent hand cooling would mitigate the rise of core body temperature and improve performance during football specific tasks.

METHODS

Participants

Twelve healthy unacclimatized males participated in this research study. Inclusion criteria were as follows: (a) 18-35 year old English speaking males (b) engaged in weight training or aerobic exercise 3 times per week or > 6 hours per week. The exclusion criteria included: (a) chronic health problems, (b) previous history of exertional heat stroke in the last 3 years, (c) history of cardiovascular, metabolic or respiratory disease, and (d) current musculoskeletal injury limiting physical activity. Participants' age in years (yrs), height in centimeters (cm), and body mass in kilograms (kg) were measured. Percentage of body fat (%BF) and lean mass (LBM) 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). DEXA measurements were performed by a trained technician following

standard procedures, according to the manufacturer's guidelines, while the participant was lying in a supine position. Participant demographics are presented in Table 2. This laboratory study was conducted in accordance with the university's International Review Board (IRB). Participants completed an informed consent and a medical history questionnaire prior to participation.

Table 2- Subject demographic info collected during familiarization session. Body fat % and Lean body mass % obtained from DEXA scan results.

Demographics of Subjects (mean \pm SD) n=12				
Height (cm)	Mass (kg)	Age (yr)	Body fat mass %	Body Lean mass %
179 \pm 5	83.1 \pm 10.0	24 \pm 4	19 \pm 7	78 \pm 6

Protocol

Participants attended four sessions, one familiarization session and three testing sessions separated by a minimum of one week (Figure 20). The treatment order was randomized and counterbalanced. Participants executed the performance tasks as described followed by a 90 minute treadmill protocol with one of three treatment conditions, 1) Control (Ctrl) 2) Hand cooling (HC) and 3) Hand cooling with fluid replacement (HCF). Physiological variables such as heart rate (HR), T_{RE} , skin temperature (T_{skin}) as well as perceptual scales (Rating of Perceived Exertion (RPE), Thermal, Thirst, Pain, Fatigue, Environmental Symptom Questionnaire (ESQ)) were recorded. Dependent variables specific to football performance included power using the countermovement vertical jump (CMJV) test, speed using a 6-second sprint (SPT) on a non-motorized treadmill, agility using both a fast feet drill (FF) and a reaction drill (REACT), and balance using the modified balance error scoring system (BESS).

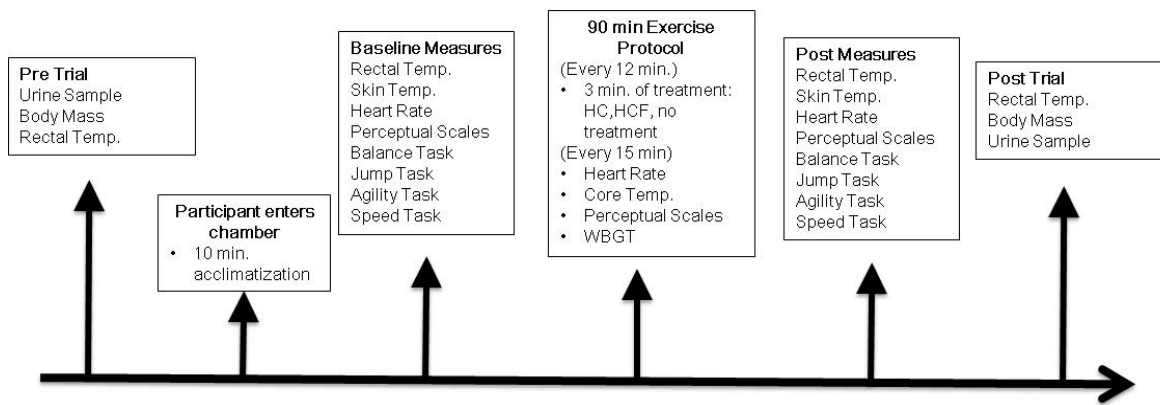


Figure 20- Flow chart for all three testing sessions. Only variability during these sessions was the treatment received between exercising bouts for the HCF, HC, Ctrl groups.

Familiarization Session

Participants arrived in the same clothing and shoes they would wear under the equipment for each session. Each participant was properly fitted with a Football Helmet (Riddell; Speed), shoulder pads (Riddell; Power CPX 30), football pants (Nike; Team Apparel [with internal tailbone, Hip (Adams USA), Thigh (Bike) and Knee (Schutt) pads]) and football jersey (Nike; Team Apparel) over top of the shoulder pads.

Throughout the testing protocol participants were monitored via a rectal thermometer (YSI Spring Instruments, TX), heart rate monitor (Timex Group USA Middlebury, CT), and T_{skin} digital thermometers (Thermochron iButton +15°C thru +46°C Embedded Data Systems, KY USA). Upon arrival to the lab, participants provided a urine sample and inserted the calibrated flexible rectal thermometer 10 cm beyond the anal sphincter prior to beginning each session. Hydration status was confirmed using a hand held refractometer (Atago 300 CL, Atago, Japan) for urine specific gravity (Usg). Prior to each exercise session all participants were required to begin exercise with a Usg of ≤ 1.020 , and if they did not their testing session was rescheduled for a later date. Pre and post-exercise body mass was measured using a calibrated scale (model BWB-800A; Tanita Corp, Tokyo, Japan) to the 0.01kg, in order to determine percent body mass loss (% BML) and to determine fluid needs for the HCF trial. T_{sk} was measured in six locations on the right side of the body (chest, deltoid, thigh, calf, right and left hands)

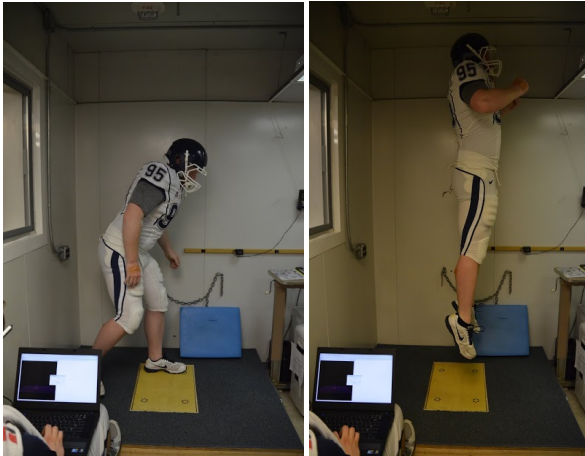
using the surface digital thermometers attached by 3.8 cm x 6 cm strips of tape (Leukotape L,BSN Medical South Africa). Thermometer buttons were placed specifically in the following locations: 1) half way between the coracoid process and the nipple 2) over the insertion of the deltoid muscle 3) half way between and in line with the anterior superior iliac spine (ASIS) and the superior pole of the patella 4) half way between and in line with the calcaneal tuberosity and the joint line of the knee, and 5-6) on left and right hands were placed on the dorsal surface, along the mid-shaft of the 3rd metacarpal.

Participants donned the football equipment and completed an abbreviated 30-minute exercise protocol, which consisted of walking on a treadmill (Precor, Woodinville, VA) at a speed (3.5-4.5mph) and incline (5%). Participants were instructed to walk at a pace that they could sustain for the full 90 minutes but at an intensity that was moderately hard. This was to ensure that their core body temperature were to rise in hopes of them finishing exercise at or near 40°C. This method takes into account individual variation in stride length and rate of metabolic heat production. The rate of rise in core temperature was calculated by taking T_{RE} every 6 minutes. The speed of the treadmill was adjusted during the familiarization trial if need be to ensure that all subjects were going to achieve the desired T_{RE} that the investigators were looking to achieve. Once the speed was pinpointed it remained constant for all three testing trials

To familiarize subjects on use of the hand-cooling device and the timing of using the device during the exercise, subjects were shown the proper way to use the CoreControl device during the familiarization session. All participants placed their right hand into the hand-cooling device for a duration of 3 minutes to simulate one bout of cooling. All instructions for use were performed in accordance with the recommendations made from the manufacturer. During testing, one researcher was blinded to the treatment and left the room while a second researcher entered the room to administer the treatment. During the control condition the device was worn by the participants but

remained in the “off” position. During all treatments the participants remained seated to ensure body positioning was consistent. Participants were familiarized with perceptual scales of thirst, thermal sensation, fatigue, pain, environmental symptoms questionnaire (ESQ) and ratings of perceived exertion (RPE) as used in previous studies.^{66, 67, 68, 69,70,71,72} Participants were also instructed on the correct procedures for the performance battery, which consisted of 5 specific tests aimed to examine power, agility, speed, and balance. Each performance task (CMVJ, BESS, FF/REACT drills, SPT) was performed until the participant was able to properly perform the task. This was done to minimize the learning bias during the testing trials and ensure subject safety.

Counter Movement Vertical Jump Task- The first performance assessment was a CMVJ using a non-conductive force plate (model 4060-NC; Bertec Corporation, Columbus, OH) controlled by Motion Monitor software (Innovative Sports Technology, Chicago, IL) during the balancing tasks. The force plate measured the vertical ground reaction force (VGRF) and collected kinetics at sampling frequencies of 1000 Hz during the performance of the CMVJ. This has been shown to be valid and reliable when assessing power in a CMVJ (ICC= 0.861).^{112,113} The peak vertical ground reaction force will be normalized to body weight (N) for each participant (% body weight). Velocity and power were calculated from the VGRF data using the impulse-momentum theorem.¹¹³ The CMVJ required participants to stand with both feet on the force plate remaining still while calibration took place. On cue the participant would step back with their dominate leg while simultaneously lowering their hips and swinging both arms backward. In one fluid motion participants would step back to the starting position with their dominate foot and drive arms forward as they jumped off both feet. They were instructed to leave and land with both feet on the force plate. Participants were asked to perform the CMVJ in duplicate, however, additional attempts were required if the task was performed incorrectly.



Modified Balance Error Scoring System Test- The modified BESS test was chosen to evaluate balance and postural control because of its high reliability and reproducibility (ICC =0.71; without DL stance).¹¹⁴ The BESS test assessed the participant's balance with two different stances on two surfaces. The two stances included: Single Leg Stance (SLS), and Tandem Stance (TS). The SLS required participants to stand on one foot with their contralateral hip flexed 30 degrees and knee flexed 45 degrees. The TS required participants to stand with the heel of their dominate foot touching the toes of their non-dominate foot keeping both feet in line with each other. The two surfaces used were a firm, flat surface and a foam pad.

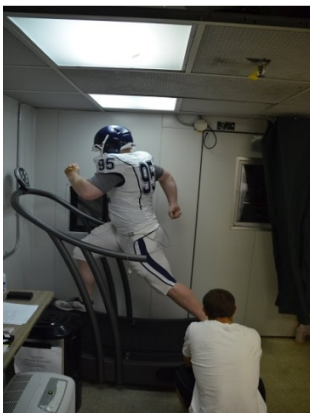
Participants were instructed to assume the standard testing position of eyes closed and hands on their hips and remain as still as possible for 20 seconds. Participants were scored based on the number of errors they performed during the 20-second time period. Errors included: lifting hands off the iliac crest, opening the eyes, stepping, stumbling, or falling, moving the hip into more than 30 degrees of flexion or abduction, lifting the forefoot or heel, or remaining out of the testing position for more than 5 seconds. If a participant could not maintain the standard position for at least 5 seconds, the maximum score of 10 was given. Participants completed 2 attempts 2 for each SLS and TS on both firm and foam surfaces. Each BESS test was videotaped and exported where it was then scored separately by 2 certified athletic trainers familiar with grading of the BESS with a Kappa score of agreement=1.000.



Agility FF/ REACT Drill- The two agility tests on the Quick Feet Board (The Quick Board LLC) (FF and REACT) were chosen because they are a reliable and accurate predictor of agility ($ICC = 0.89$).⁵⁷ Both agility performance tasks required participants to utilize a feedback device connected to the Quick Feet Board. The board consisted of a mat positioned on the ground with the sensor pads in five locations (upper right and left, lower right and left, and center). A control device connected to the mat provided visual stimulus (five bright lights that correspond to the five foot pads) and feedback information as the movements were performed. Participants performed two attempts of the FF drill, which required them to perform the maximum number of foot touches during a 10-second interval. The maximum number of touches was recorded by The Quick Board and each attempt was separated by 30 seconds. Participants were then asked to perform two attempts of the REACT drill, which consisted of reacting to the visual stimulus on the control device. The numbers of correct and incorrect touches were counted during the 10 second trial and were recorded by the Quick Board Software (The Quick Board, LLC). So, we can assume that the measurements obtained on the Quick Feet Board would directly correlate to performance on the football field during drills requiring change in direction.¹¹⁴



6 second Non-motorized Treadmill Sprint- The SPT task was performed on a Woodway Curve (The Curve, Woodway, USA, Waukesha, WI), non-motorized treadmill (NMT). With close replication of physiological workload and direct correlation to football play, the 6-s sprint test was an accurate indicator of football performance by utilizing maximum sprint speed (ICC = 0.941).⁵⁸ Prior to each sprint participants walked for 5 seconds, then ramped up their speed until maximum speed was obtained over a period of 10 seconds. Participants were asked to maintain the maximal effort for a minimum of 6 seconds and then decelerate to a slow walk for 45 seconds of active recovery between each sprint task.⁵⁸ Top speed was recorded for each 6- second sprint task using a hand held digital tachometer (Ametek USA, Largo, Florida).



Hand Cooling Device

The hand cooling treatment device (Core Control, AVAcore Technologies, Ann Arbor, MI) utilized in this study consisted of a rigid chamber connected to a vacuum and water pump in which one hand could be inserted through an elastic structure forming an airtight seal around the forearm. The chamber is lined with bladders that surround the hand filled with cold circulating water maintained at (16.4°C). Once the seal is created the device maintains a slight sub-atmospheric pressure (-40 mm Hg) through a vacuum pump. Both the circulating cold water and the suction are controlled through tubing secured to the chamber.



Testing Session

Upon arrival for the testing sessions, subjects provided a urine sample and inserted the rectal thermistor as instructed during the familiarization session. The HR strap, T_{skin} sensors, and standard football game attire were placed on the participants. Once in place, the participants entered the temperature controlled environmental chamber (minute 0; temperature 38.44 ± 0.11 °C, relative humidity $34.94 \pm 0.31\%$) and equilibrated for 10 minutes to allow for equilibration. Baseline measures of

T_{RE} , heart rate, and perceptual scales were obtained followed by two correct attempts of the pre-performance battery tasks (CMVJ, BESS Test, FF drill, REACT Drill, SPT).

T_{RE} , heart rate, and perceptual scales were obtained prior to commencement of the 90-minute treadmill protocol, every 12th minute of exercise a three minute treatment session occurred. T_{RE} , HR, and perceptual scales were recorded just prior to the completion of each treatment bout. The participant would exit the treadmill and remain seated with the treated arm resting on the thigh in a relaxed position for the duration of the treatment. Immediately after treatment participants re-entered the treadmill and continued exercising, for HCF group participants were asked to consume a bolus of water (21°C, 70°F) equal to sweat rate divided equally between the 6 treadmill bouts. Following the 90-minute treadmill protocol, the performance tasks (CMVJ, BESS Test, FF drill, REACT Drill, SPT) were performed again. T_{RE} , HR, and the perceptual scales were measured again immediately post-performance tasks. Participants then exited the chamber; a post-exercise nude body mass, urine sample were obtained and rectal probe was removed.

DATA REDUCTION AND STATISTICAL ANALYSIS

All data were analyzed using SPSS version 21.0 (IBM Corporation, Champaign, IL, USA) with an a-priori level alpha level of 0.05. We performed separate (condition x time) repeated-measures ANOVA for physiological, perceptual and performance dependent variables. All repeated measures ANOVAs were corrected using a Bonferroni post hoc test to evaluate any significant differences. Furthermore mean differences with 95% confidence intervals and cohen's-d effect sizes were utilized to quantify the magnitude of the difference between the conditions. One way ANOVA with Bonferroni post hoc tests was utilized to examine Delta values (Post value minus Pre value) and percent change scores were calculated to further quantify the difference between the conditions. CMVJ force plate data were then exported into a customized software program (MatLab, The Mathworks; Boston, MA) and filtered using

a low-pass, second-order 10 Hz Butterworth filter. The errors for each BESS position were summed to result in a Total BESS score, as well as individual scores for each position.

RESULTS

Body Mass, Urine Color and Urine Specific Gravity

Independent of time, we observed differences between conditions for body mass ($F_{2,22}=125.07$, $p=0.001$). Independent of condition, we observed differences between time points for body mass ($F_{1,11}=32.84$, $p=0.0001$). In order to ensure accuracy across groups, percentage of body mass loss (%BML) was calculated for each condition using PRE and POST nude body mass. The %BML (mean \pm SD) was higher for the Ctrl and HC conditions HC= $3.08 \pm 0.59\%$, Ctrl= $3.29 \pm 0.68\%$ than the HCF condition $1.60 \pm 0.53\%$. Mean difference (MD) and 95% confidence intervals (95%CI) indicated meaningful differences between [HCF-HC] 1.48% (0.86 to 2.10) $p=0.001$ and [HCF-Ctrl] 1.69% (1.07 to 2.31) $p=0.001$. (Figure 21)

Independent of time, we observed differences between conditions for urine color ($F_{2,22}=3.597$, $p=0.047$). Independent of condition, we observed differences between time points for urine color ($F_{1,11}=4.014$, $p=0.021$). The PRE urine color MD (95%CI) for [HCF-HC] was -0.33 (-1.43 to 0.75) $p = 1.000$ while [HCF-Ctrl] was 0.25 (-0.85 to 1.35) and [HC-Ctrl] was 0.58 (-0.52 to 1.68) $p = 0.57$.

No significant interactions were observed over time points or between conditions for Urine specific gravity (USG). There were no significant differences (mean \pm SD) ($p > 0.05$) in PRE USG values between subjects in any of the conditions (HCF= 1.014 ± 0.006 , HC= 1.017 ± 0.008 , Ctrl= 1.015 ± 0.006) or POST USG values (HCF= 1.016 ± 0.006 , HC= 1.017 ± 0.006 , Ctrl= 1.015 ± 0.006) (Figure 22).

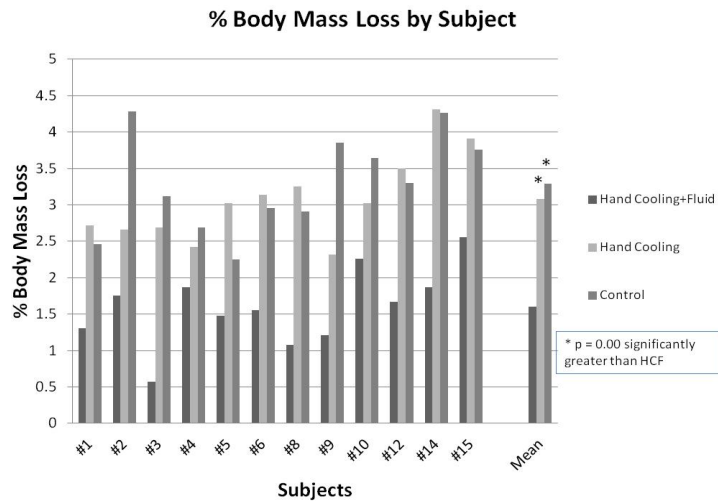


Figure 21- Calculated % Body Mass Loss (%BML) by participant for all conditions. The mean %BML difference between groups for HCF vs. HC, HCF vs. Con and HC vs. Con was -1.48,-1.69 and -0.21 respectively. * Significant differences between HCF, HC vs. Control ($p \leq 0.05$).

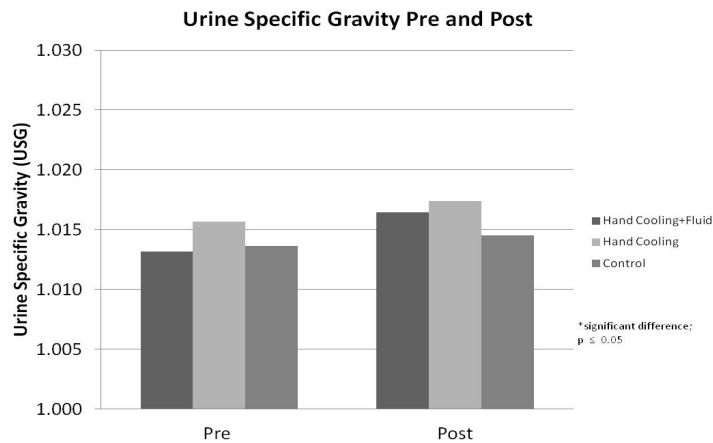


Figure 22- Mean urine specific gravity (USG) for all conditions hand cooling with fluid (HCF), hand cooling only (HC), control (CON). No significant difference for mean PRE or POST USG ($p=0.00$). *= Significant differences between HCF, HC vs. Control ($p \leq 0.05$).

Rectal Temperature

We observed a significant interaction between time points and conditions for T_{RE} ($F_{38,418} = 2.674$, $p = 0.049$) (Figure 23). Independent of time, we observed differences between conditions for T_{RE} ($F_{2,22} = 6.482$, $p = 0.018$). Independent of conditions, we observed differences between time points for T_{RE} ($F_{19,209} = 166.110$, $p = 0.001$). T_{RE} was highest during the Ctrl condition starting at minute 66 compared to the HCF condition. (Figure 23) T_{RE} was similar ($p > 0.05$) at baseline between groups (mean \pm SD) (HCF = $37.22 \pm 0.28^\circ\text{C}$, HC = $37.17 \pm 0.35^\circ\text{C}$, Ctrl = $37.18 \pm 0.29^\circ\text{C}$). Upon exiting the environmental chamber POST T_{RE} was HCF = $38.64 \pm 0.39^\circ\text{C}$, HC = $38.86 \pm 0.45^\circ\text{C}$, and Ctrl = $39.24 \pm 0.45^\circ\text{C}$.

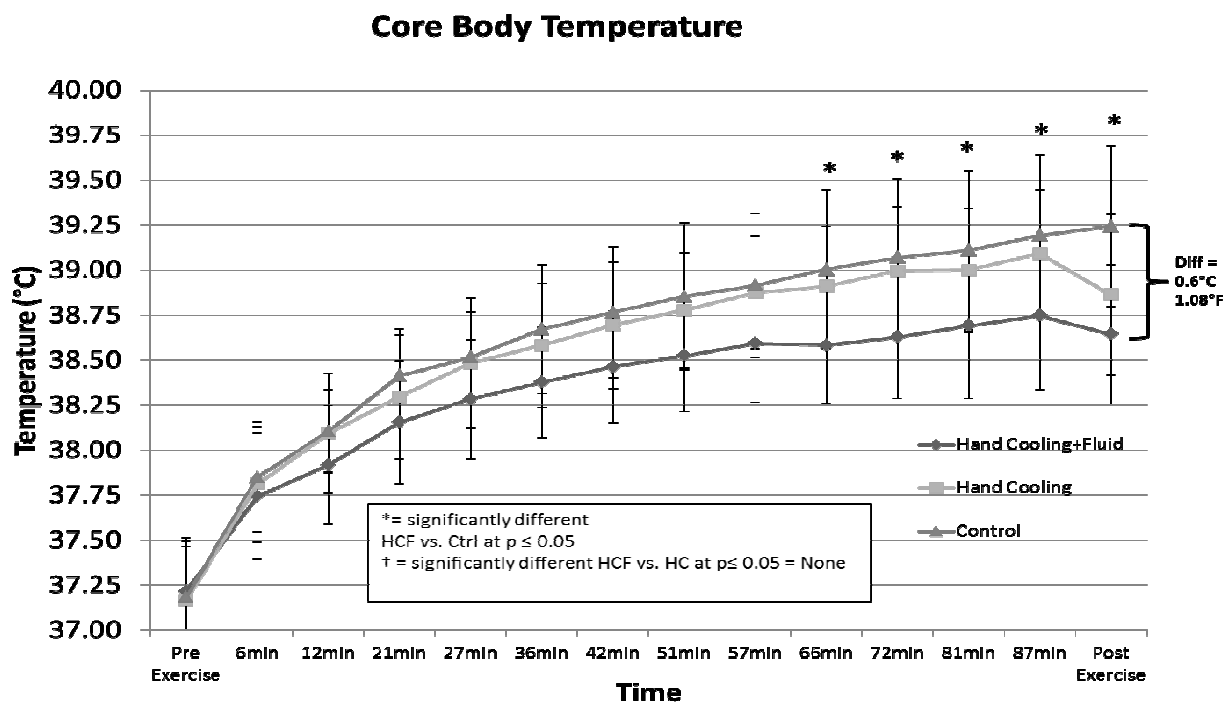


Figure 23- Rectal body temperature changes over time during exercise for all conditions hand cooling and fluid (HCF), hand cooling only (HC), control (Ctrl). A difference of 0.6°C is noted at the end of exercise for HCF-Ctrl.

Mean differences, 95% confidence intervals and effect sizes between conditions for T_{RE} are presented in Table 1. Both Table 3 and Figure 23 indicate that POST [HCF-Ctrl] was -0.60°C (-1.04 to -0.16), $p=0.024$, $ES=1.43$, which began to diverge from Ctrl starting at minute 66 [HCF-Ctrl] -0.42°C (-0.80 to -0.04), $p=0.026$, $ES= 1.08$. At POST the HCF group had a 0.6°C (1.08°F) reduced body temperature compared to Ctrl. There were no significant mean differences in T_{RE} between the HC vs. Ctrl conditions at any time point. ΔT_{RE} PRE to POST was $1.43 \pm 0.35^{\circ}\text{C}$, $1.70 \pm 0.48^{\circ}\text{C}$ and $2.06 \pm 0.40^{\circ}\text{C}$ for HCF, HC and Ctrl respectively. ΔT_{RE} MD (95%CI) from the PRE exercise time point to minute 87 (immediate post treadmill exercise) for [HCF-HC] and [HC-Ctrl] were -0.41°C (-0.86 to 0.04), $p=0.088$, and -0.09°C (-0.54 to 0.37) $p= 1.00$, while [HCF-Ctrl] observed a greater mean difference of -0.50°C (-0.95 to -0.04) $p = 0.028$. Furthermore, when examining the mean difference (95%CI) in ΔT_{RE} from the PRE exercise time point to the POST exercise time point just prior to leaving the chamber [HCF-HC] and [HC-Ctrl] were -0.27°C (-0.69 to 0.15) $p=0.347$, $ES= 0.65$ and -0.36°C (-0.78 to 0.06) $p= 0.114$, $ES= 0.85$ while [HCF-Ctrl] demonstrated a larger difference of -0.63°C (-1.06 to -0.21) $p = 0.002$, $ES=1.75$.

The change in T_{RE} for each additional 1% body mass loss ($\Delta \cdot 1\% \text{BML}^{-1}$) was calculated for the HCF trial compared to the HC and Ctrl groups. $\Delta \cdot 1\% \text{BML}^{-1}$ for [HCF-HC] was $0.18^{\circ}\text{C} \cdot 1\%^{-1}$ while [HCF-Ctrl] was $0.37^{\circ}\text{C} \cdot 1\%^{-1}$. If T_{RE} is projected for each group the: a 5% BML in the HC group would result in a T_{RE} of 40.86°C (105.5°F), a 4% and 5% projected BML for the Ctrl group would cause a POST T_{RE} of 40.68°C (105.22°F) and 41.45°C (106.61°F) respectively (Table 4).

The change in T_{RE} for each of the six cooling treatments was determined and no significant differences ($p>0.05$) in T_{RE} existed for any of the conditions. However, the overall the data trends toward an increase in heat removal during subsequent treatments (Figure 24).

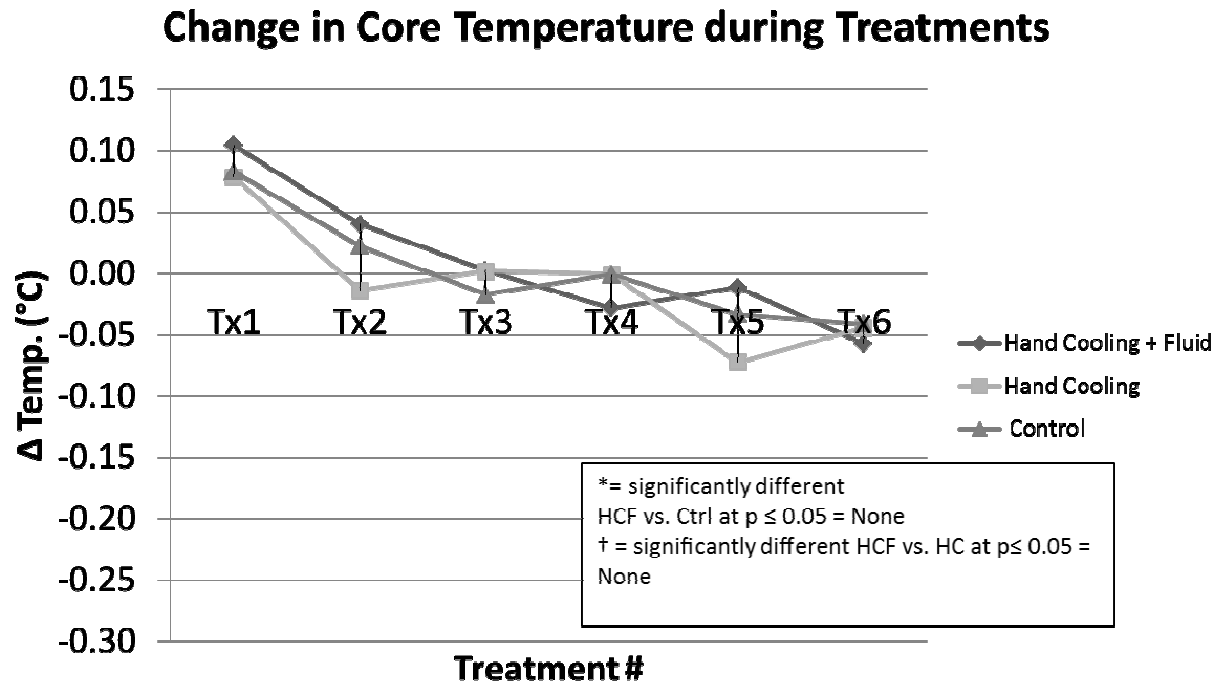


Figure 24- Change in core temperature (T_{RE}) over the course of the 3 min treatments for all conditions hand cooling and fluid (HCF), hand cooling (HC) and control (Ctrl). T_{RE} was measured before and after each of the 6 treatment sessions. A (+) difference indicates heat gain and a (-) difference indicates heat loss.

Table 3- Mean difference in Rectal temperature (°C) for all time points during the testing sessions by condition HCF, HC, Ctrl. Variable measured at baseline (PRE); halfway through, at the end of each 12 minute treadmill bout and immediately after treatment session (minutes), and after post-performance tasks (POST). Significant difference HCF-Ctrl starting at minute 66 to POST. Symbol (‡) indicates strong effect size (0.8). Symbol (†) indicates moderate effect size (0.5). Symbol (*) indicates small effect size (0.2). Symbol (**) indicates significantly different HCF versus Ctrl (** p≤0.05).

Rectal Temperature Mean Difference (Degrees Celsius) (95%CI) & Effect Size

Condition	Pre	ES	6 min	ES	12 min	ES	15 min	ES	21 min	ES
HCF-HC	0.05 (-0.26, 0.37)	0.16	-0.07 (-0.40, 0.27)	0.20*	-0.18 (-0.50, 0.14)	0.54†	-0.15 (-0.45, 0.15)	0.46*	-0.14 (-0.47, 0.19)	0.41*
HC-Ctrl	-0.02 (-0.33, 0.29)	0.05	-0.04 (-0.37, 0.30)	0.12	0.02 (-0.30, 0.34)	0.06	-0.06 (-0.36, 0.24)	0.20*	-0.12 (-0.44, 0.21)	0.29*
HCF-Ctrl	0.03 (-0.28, 0.34)	0.12	-0.11 (-0.44, 0.23)	0.32*	-0.16 (-0.48, 0.16)	0.53†	-0.21 (-0.51, 0.09)	0.78†	-0.26 (-0.59, 0.07)	0.85‡

Condition	27 min	ES	30 min	ES	36 min	ES	42 min	ES	45 min	ES
HCF-HC	-0.2 (-0.53, 0.13)	0.58†	-0.15 (-0.48, 0.19)	0.44*	-0.21 (-0.55, 0.14)	0.63†	-0.23 (-0.58, 0.12)	0.7†	-0.23 (-0.58, 0.12)	0.70†
HC-Ctrl	-0.03 (-0.36, 0.29)	0.11	-0.07 (-0.41, 0.26)	0.22*	-0.09 (-0.44, 0.26)	0.26*	-0.07 (-0.42, 0.28)	0.20*	-0.05 (-0.40, 0.30)	0.15
HCF-Ctrl	-0.23 (-0.56, 0.09)	0.80‡	-0.22 (-0.55, 0.12)	0.66†	-0.30 (-0.64, 0.05)	0.89‡	-0.30 (-0.66, 0.05)	0.9‡	-0.28 (-0.63, 0.07)	0.82‡

Condition	51 min	ES	57 min	ES	60 min	ES	66 min	ES	72 min	ES
HCF-HC	-0.25 (-0.61, 0.11)	0.80‡	-0.28 (-0.64, 0.08)	0.89‡	-0.23 (-0.59, 0.12)	0.71†	-0.33 (-0.71, 0.05)	1.00‡	-0.37 (-0.76, 0.02)	1.07‡
HC-Ctrl	-0.08 (-0.44, 0.28)	0.21*	-0.04 (-0.40, 0.32)	0.11	-0.11 (-0.47, 0.24)	0.32*	-0.09 (-0.47, 0.29)	0.24*	-0.07 (-0.46, 0.32)	0.19
HCF-Ctrl	-0.33 (-0.69, 0.03)	0.91‡	-0.32 (-0.68, 0.04)	0.88‡	-0.35 (-0.71, 0.01)	0.97‡	-0.42 (-0.80, -0.04)**	1.08‡	-0.44 (-0.83, -0.05)**	1.13‡

Condition	75 min	ES	81 min	ES	87 min	ES	90 min	ES	Post	ES
HCF-HC	-0.31 (-0.68, 0.06)	0.95‡	-0.31 (-0.72, 0.10)	0.84‡	-0.34 (-0.76, 0.07)	0.89‡	-0.3 (-0.73, 0.12)	0.81‡	-0.22 (-0.66, 0.22)	0.52†
HC-Ctrl	-0.11 (-0.48, 0.26)	0.30*	-0.11 (-0.52, 0.30)	0.28*	-0.10 (-0.52, 0.32)	0.24*	-0.17 (-0.60, 0.25)	0.41*	-0.38 (-0.82, 0.06)	0.85‡
HCF-Ctrl	-0.42 (-0.79, -0.05)**	1.13‡	-0.42 (-0.83, -0.01)**	0.99‡	-0.45 (-0.86, -0.03)**	1.04‡	-0.48 (-0.90, -0.05)**	1.08‡	-0.60 (-1.04, -0.16)**	1.43‡

Heart Rate

Independently of time, we observed differences between conditions for heart rate (HR) ($F_{2,22} = 4.552$, $p=0.044$). Independent of condition, we observed differences between time points for HR ($F_{7,77} = 232.836$, $p=0.001$). No significant differences in HR between conditions for any time point ($p>0.05$). There was a point at the 90 min mark during exercise that HR crossed as HCF increased while HC and Ctrl both decreased not at a significantly different level ($p>0.05$) (Figure 25). From minute 57-87 of the treadmill walking protocol, HR mean differences between [HCF-Ctrl] ($p>0.05$) were [MD (CI), ES] -8 bpm (-22.46, 5.96) 0.58, -13 bpm (-27.02, 1.68) 0.88, -10 bpm (-25.92, 5.42) 0.72, 4 bpm (-23.51, 15.18) 0.26 respectively (Table 5). The Δ HR for HCF, HC, Ctrl was 71 bpm, 79 bpm, 82 bpm respectively. When normalized to BML the $\Delta \cdot 1\% \text{BML}^{-1}$ for [HCF-HC] and [HCF-Ctrl] was -6.03 ± 10.31 bpm and -7.41 ± 8.14 bpm for every 1% respectively.

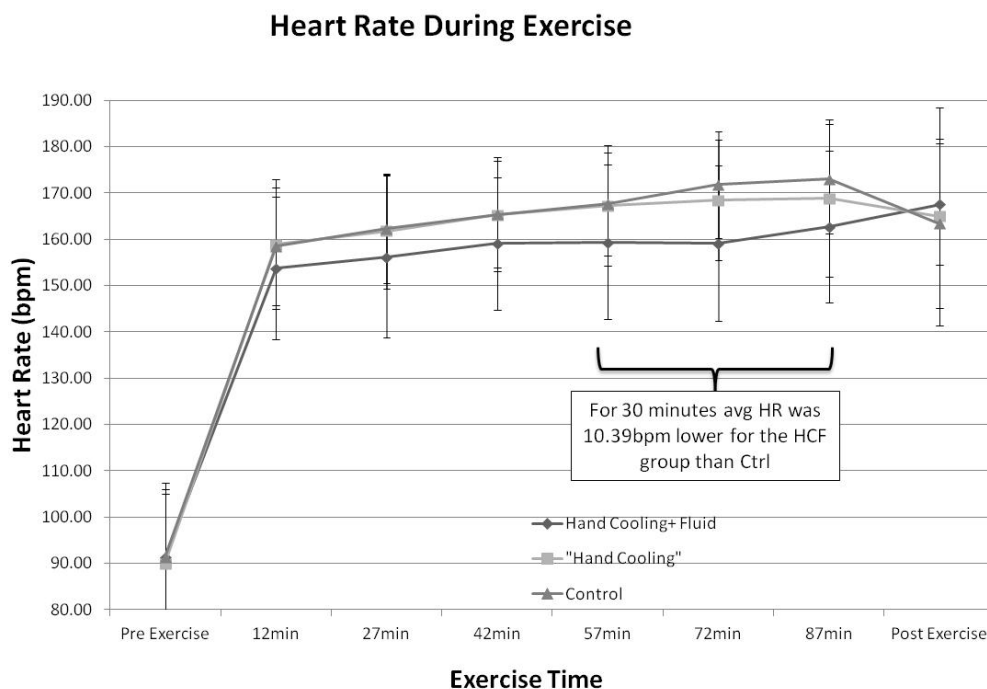


Figure 25- Heart Rate (HR) measured during exercise for HCF, HC, Ctrl conditions. Each time point shown is immediately prior to each of the 6 treatment sessions. Significant differences between HCF, HC vs. Control ($p \leq 0.05$).

Table 5- Calculated heart rate (HR) mean differences with 95% CI and ES for all conditions Hand cooling with fluid (HCF) vs. hand cooling (HC), hand cooling (HC) vs. control (Ctrl), hand cooling with fluid (HCF) vs. control (Ctrl). Symbol (‡) indicates strong effect size (0.8). Symbol (†) indicates moderate effect size (0.5). Symbol (*) indicates small effect size (0.2). Symbol (**) indicates significantly different HCF versus Ctrl (** p≤0.05).

Heart Rate Mean Difference (95%CI) & Effect Size

Conditions	Pre	ES	12 min	ES	27 min	ES	42 min	ES
HCF-HC	1.25 (-14.46, 16.96)	0.08	-5.17 (-19.69, 9.36)	0.35*	-5.58 (-20.09, 8.93)	0.37*	-6.25 (-19.40, 6.90)	0.47*
HC-Ctrl	-1.25 (-16.96, 14.46)	0.08	0.5 (-14.02, 15.02)	0.04	-0.42 (-14.93, 14.09)	0.03	-0.08 (-13.23, 12.06)	0.01
HCF-Ctrl	0.00 (-15.71, 15.71)	0.00	-4.66 (-19.19, 9.85)	0.33*	-6.00 (-20.51, 8.51)	0.40*	-6.33 (-19.47, 6.81)	0.49*
Conditions	57min	ES	72 min	ES	87 min	ES	Post	ES
HCF-HC	-7.83 (-22.04, 6.38)	0.52†	-9.33 (-23.68, 5.02)	0.62†	-6.08 (-21.75, 9.58)	0.37*	2.58 (-16.76, 21.93)	0.14
HC-Ctrl	-0.41 (-14.63, 13.79)	0.03	-3.33 (-17.68, 11.02)	0.27*	-4.17 (-19.83, 11.50)	0.28*	1.58 (-17.76, 20.93)	0.08
HCF-Ctrl	-8.25 (-22.46, 5.96)	0.58†	-12.67 (-27.02, 1.68)	0.88‡	-10.25 (-25.92, 5.42)	0.72†	4.17 (-23.51, 15.18)	0.26*

Performance Battery

Table 6- Raw scores (mean \pm SD) of all performance tasks for each condition hand cooling with fluid (HCF), hand cooling only (HC), and control (Ctrl). REACT=Reaction Drill, FF=Fast Feet Drill, CMVJ= Counter Movement Vertical Jump, BESS = Balance Error Scoring System.

Performace Task Mean \pm SD

Pre Exercise Measures								
	REACT Time (secs)	REACT Total Touches	REACT Misses	FF- Touches	BESS	SPT	CMVJ Ht	CMVJ VGRF
HCF	0.57 \pm 0.06	14.17 \pm 1.40	0.63 \pm 0.80	108.54 \pm 6.04	14.42 \pm 5.30	15.77 \pm 0.71	27.7 \pm 5.1	2618.52 \pm 956.45
HC	0.55 \pm 0.05	14.63 \pm 1.11	0.96 \pm 0.84	104.54 \pm 6.49	13.75 \pm 6.06	15.70 \pm 0.50	28.0 \pm 4.2	2809.95 \pm 429.35
Ctrl	0.55 \pm 0.04	14.42 \pm 0.90	0.54 \pm 0.69	108.17 \pm 5.73	15.00 \pm 6.33	16.07 \pm 0.57	28.8 \pm 6.4	2864.24 \pm 507.88
Post Exercise Measures								
	REACT Time (secs)	REACT Total Touches	REACT Misses	FF- Touches	BESS	SPT	CMVJ Ht	CMVJ VGRF
HCF	0.55 \pm 0.06	14.58 \pm 1.38	0.96 \pm 0.86	110.04 \pm 5.97	13.38 \pm 5.43	16.00 \pm 0.83	30.1 \pm 6.1	2952.29 \pm 570.49
HC	0.57 \pm 0.06	14.21 \pm 1.29	0.63 \pm 0.71	108.08 \pm 6.60	14.41 \pm 5.08	15.59 \pm 1.29	30.1 \pm 6.6	2850.87 \pm 564.17
Ctrl	0.56 \pm 0.06	14.21 \pm 1.29	1.04 \pm 0.92	105.75 \pm 11.06	18.96 \pm 8.47	15.49 \pm 0.40	30.7 \pm 5.3	2920.92 \pm 510.34

Table 7- Calculated mean differences for each performance task with 95% CI and ES. Hand cooling with fluid (HCF) vs. hand cooling (HC), hand cooling (HC) vs. control (Ctrl), hand cooling with fluid (HCF) vs. control (Ctrl). (‡) indicates strong effect size (0.8). Symbol (†) indicates moderate effect size (0.5). Symbol (*) indicates small effect size (0.2). REACT=Reaction Drill, FF= Fast Feet Drill, CMVJ= Counter Movement Vertical Jump, BESS = Balance Error Scoring System.

Performance Tasks Mean Difference (95% CI); Effect Size (ES)																
Pre Exercise Measures																
	REACT Time (secs)	ES	REACT Total Touches	ES	REACT Misses	ES	FF- Touches	ES	BESS Score	ES	SPT	ES	CMVJ Height	ES	CMVJ VGRF	ES
HCF-HC	0.02 (-0.03,0.07)	0.33*	-0.46 (-1.65,0.73)	0.36*	-0.33 (-1.14,0.47)	0.41*	4.0 (-2.28,10.28)	0.64†	0.67 (-5.42,6.75)	0.12	0.08 (-0.54,0.69)	0.12	-0.35 (-5.78, 5.08)	0.08	-191.42 (-883.97, 501.12)	0.26*
HC-Ctrl	0.00 (-0.05,0.05)	0.02	0.21 (-0.98,1.40)	0.21*	0.42 (-0.39,1.22)	0.54†	-3.63(-9.90,2.65)	0.59†	-1.25 (-7.34,4.84)	0.20*	-0.38 (-0.99,0.24)	0.70†	-0.80 (-6.22, 4.63)	0.15	-54.28 (-746.84, 638.26)	0.12
HCF-Ctrl	0.02 (-0.03,0.07)	0.35*	-0.25 (-1.44,0.94)	0.21*	0.08 (-0.72,0.89)	0.11	0.38 (-5.90,6.65)	0.06	-0.58 (-6.67,5.50)	0.10	-0.30 (-0.92,0.31)	0.47*	-1.14 (-6.57, 4.28)	0.20*	-245.71 (-938.26, 446.83)	0.32*
Post Exercise Measures																
	REACT Time (secs)	ES	REACT Total Touches	ES	REACT Misses	ES	FF- Touches	ES	BESS Score	ES	SPT	ES	CMVJ Height	ES	CMVJ VGRF	ES
HCF-HC	-0.02 (-0.08,0.04)	0.35*	0.38 (-0.98,1.73)	0.28*	0.33 (-0.53,1.19)	0.42*	1.95 (-6.48,10.40)	0.31*	-1.04 (-7.73,5.66)	0.20*	0.41 (-0.54,1.35)	0.38*	0.09 (-6.01, 6.26)	0.01	101.42 (-443.22, 646.07)	0.18
HC-Ctrl	0.00 (-0.06,0.07)	0.06	0 (-1.36,1.36)	0.00	-0.42 (-1.28,0.44)	0.51†	2.33 (-6.11,10.77)	0.26*	-4.55 (-11.24,2.15)	0.65†	0.10 (-0.84,1.05)	0.11	-0.61 (-6.78, 5.56)	0.10	-70.05 (-614.70, 474.59)	0.12
HCF-Ctrl	-0.02 (-0.08,0.04)	0.30*	0.38 (-0.98,1.73)	0.28*	-0.08 (-0.94,0.78)	0.09	4.29 (-4.15,12.73)	0.48*	-5.58 (-12.28,1.11)	0.79†	0.51 (-0.43,1.46)	0.78†	-0.52 (-6.69, 5.65)	0.09	31.37 (-573.27, 576.02)	0.05

Table 8- The percent change PRE to POST for performance battery for all conditions HCF, HC, Ctrl. (‡) indicates strong effect size (0.8). Symbol (†) indicates moderate effect size (0.5). Symbol (*) indicates small effect size (0.2). REACT=Reaction Drill, FF= Fast Feet Drill, CMVJ= Counter Movement Vertical Jump, BESS = Balance Error Scoring System.

Performance Task % Change Mean Difference (95% CI); Effect Size (ES)

	REACT Time %	ES	REACT Total Touches %	ES	FF- Touches %	ES
HCF-HC	-7.1 (-15.23,1.03)	0.86‡	5.87 (-1.75, 13.48)	0.76†	-2.06 (-8.60, 4.48)	0.40*
HC-CTRL	1.13 (-6.99,9.27)	0.13	-0.01 (-7.63, 7.60)	0.00	5.83 (-0.71, 12.37)	0.82‡
HCF-Ctrl	-5.97 (-14.10, 2.17)	0.88‡	5.85 (-1.76,13.47)	0.82‡	3.77 (-2.77, 10.31)	0.56†

	BESS %	ES	SPT %	ES	CMVJ Height %	ES	CMVJ VGRF %	ES
HCF-HC	-20.50 (-52.77, 11.79)	0.84‡	2.11(-2.93,7.17)	0.38*	1.97 (-9.23,13.17)	0.18	3.07 (-3.87, 10.01)	0.41*
HC-CTRL	-16.82 (-49.10, 15.46)	0.47*	2.88 (-2.17,7.92)	0.50†	-1.02 (-12.22,10.18)	0.08	1.99 (-4.94, 8.94)	0.14
HCF-Ctrl	-37.31 (-69.60, -5.03)	1.14‡	4.99 (-0.05,10.04)	1.74‡	0.95 (-10.25,12.15)	0.11	-1.02 (-10.18, 12.22)	0.40*

Countermovement Vertical Jump: Height and Power- During the CMVJ task, a significant main effect for time ($F_{1,11}= 10.279$, $p=.008$) was observed independent of condition. POST CMVJ height was significantly higher than the PRE values regardless of condition. No significant interactions (condition x time were observed) for jump height ($F_{2,22}= 0.194$, $p=0.825$) or for power ($F_{2,22}= 1.232$, $p=0.294$).

HCF, HC, Ctrl PRE exercise VGRF had a mean of 2618.52 ± 956.45 N·m, 2809.95 ± 429.35 N·m, and 2864.24 ± 507.88 N·m respectively. POST VGRF for HCF, HC, and Ctrl was 2952.29 ± 510.49 N·m, 2850.87 ± 564.17 N·m, 2920.92 ± 510.34 N·m respectively. (Table 6) The mean difference in percent change for VGRF between groups [HCF-HC], [HC-Ctrl], [HCF-Ctrl] was 3.07% (-3.87 to 10.01); ES=0.41, -1.07% (-8.93 to 4.94); ES=0.14 and 1.99% (-4.94 to 8.93); ES=0.40 [% change (95%CI); ES] respectively (Table 8).

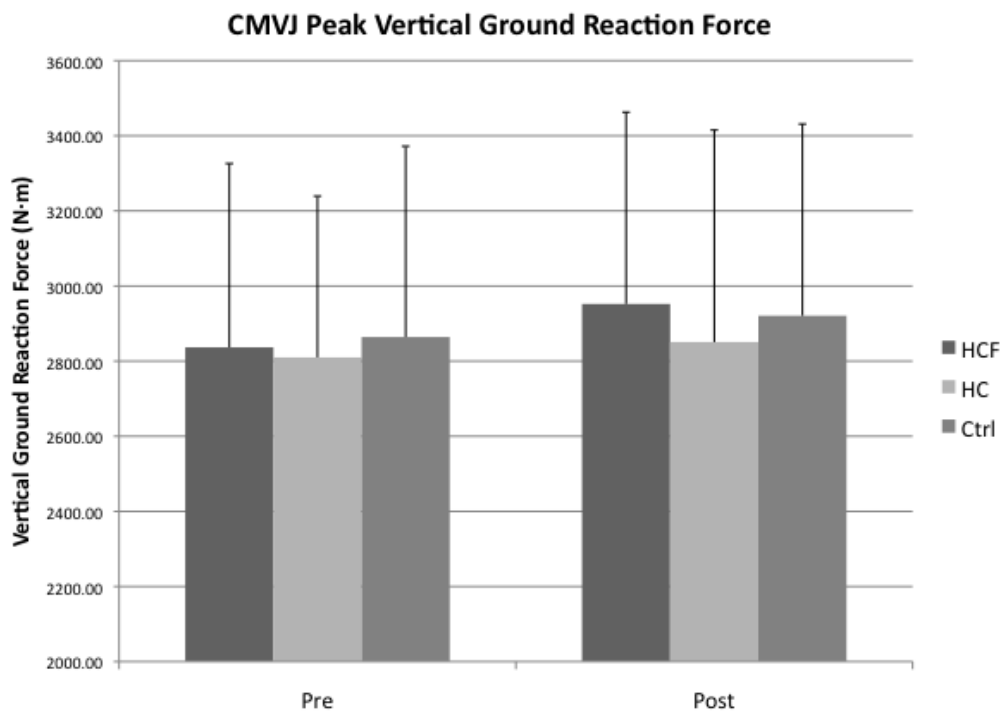


Figure 26- CMVJ (Counter Movement Vertical Jump) peak VGRF (Vertical Ground Reaction Force) from PRE to POST. (*) significantly different ($p<0.05$)

HCF, HC, Ctrl PRE exercise jump height had a mean of 27.65 ± 5.05 cm, 28.00 ± 4.17 cm, and 28.79 ± 6.35 cm respectively. POST jump heights were increased in all groups (30.14 ± 6.05 cm, 30.05 ± 6.57 cm, 30.66 ± 5.28 cm) for HCF, HC and Ctrl respectively. The mean difference in percent change for jump height between groups [HCF-HC], [HC-Ctrl], [HCF-Ctrl] was 1.97% (-9.23 to 13.17); ES=0.18, -1.02% (-12.21 to 10.18); ES=0.08 and 0.95% (-10.25 to 12.15); ES=0.11 [% change (95%CI); ES] respectively (Table 8).

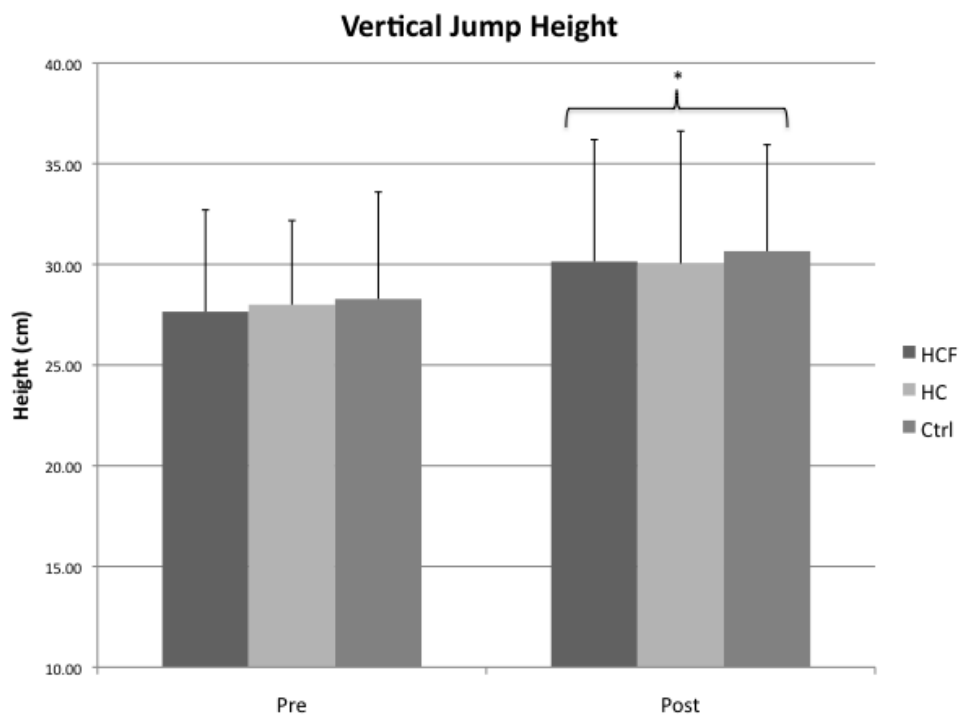


Figure 27- Vertical jump height in centimeters for PRE to POST by condition. (*)= significant main effect for time (p=0.008)

Balance Error Scoring System Task- We observed a significant interaction between time points and conditions for the total BESS score ($F_{2,22} = 3.761$, $p = 0.039$). BESS scores were highest during the Ctrl condition at POST compared with PRE. Furthermore, independent of condition, we observed differences between time points for the total BESS score ($F_{1,11} = 4.944$, $p = 0.048$) and for the SL FIRM errors ($F_{1,11} = 5.191$, $p = 0.044$). Independent of time point, we observed differences in errors between conditions during the SL FIRM stance ($F_{2,22} = 3.512$, $p = 0.047$). There were no significant differences ($p > 0.05$) for delta (PRE to POST) BESS scores between groups HCF, HC, Ctrl. The percentage change in errors within groups from (PRE to POST) for HCF, HC and Ctrl were $7.17 \pm 19.39\%$ less errors, $13.31 \pm 28.28\%$ more errors and $30.13 \pm 42.10\%$ more errors respectively (Figure 28).

HCF, HC, Ctrl PRE exercise BESS had a mean of 14.42 ± 5.30 errors, 13.75 ± 6.06 errors, 15.00 ± 6.33 errors respectively. POST BESS test scores for HCF, HC, Ctrl were 13.38 ± 5.43 errors, 14.41 ± 5.08 errors and 18.96 ± 8.47 errors respectively (Table 6) The percent change in errors between groups [HCF-HC], [HC-Ctrl], [HCF-Ctrl] PRE to POST exercise was -20.50% (-52.77 to 11.79); 0.84 , -16.82% (-49.10 to 15.46); 0.47 and -37.31% (-69.60 to -5.03); 1.14 [% change (95%CI);ES] respectively (Table 8).

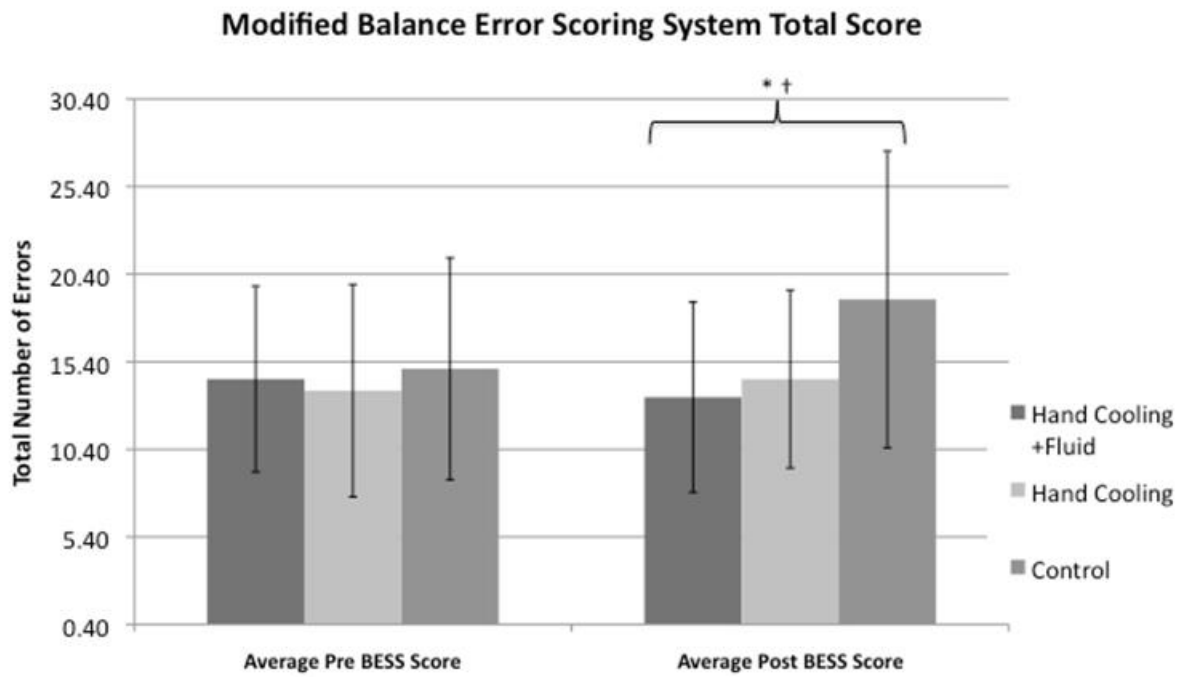


Figure 28- Modified BESS Scores for PRE and POST for all conditions HCF, HC, Con. (*)= significant main effect for time ($p=0.048$). (†) = significant group x time interaction ($p=0.033$)

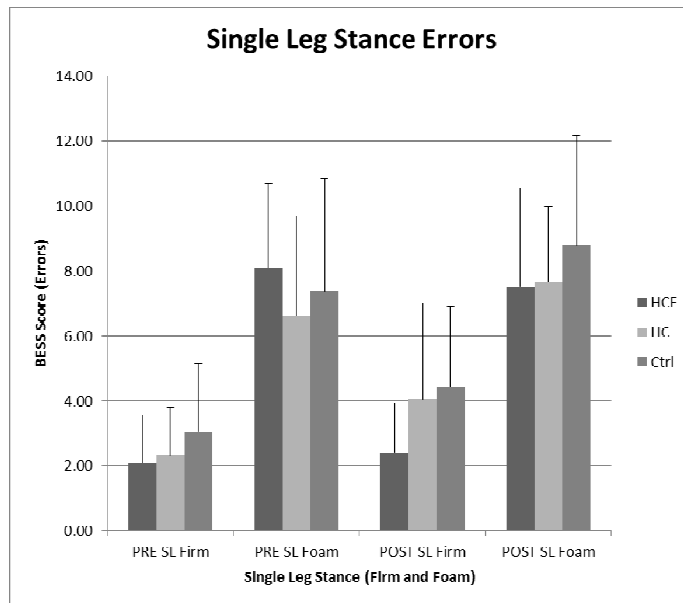


Figure 29- Number of errors for PRE and POST single leg stance (SL) tasks (foam and firm) for all conditions HCF, HC, Ctrl.

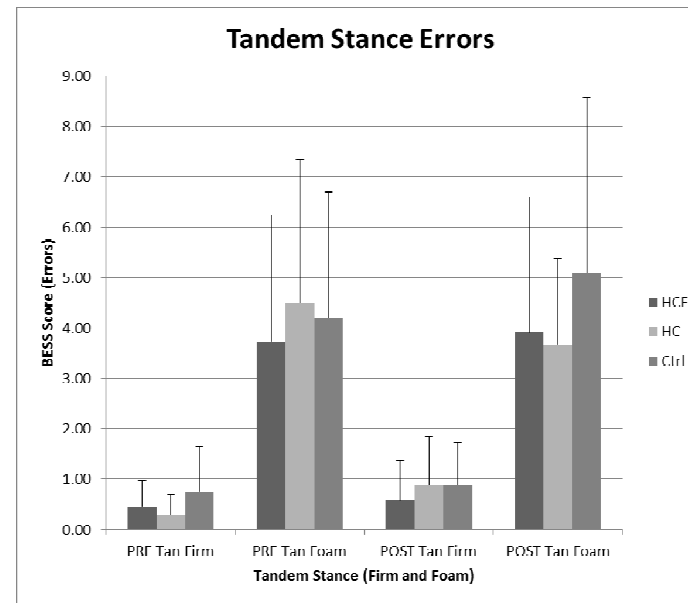


Figure 30- Number of errors for PRE and POST tandem stance (TAN) tasks (foam and firm) for all conditions HCF, HC, Ctrl.

Table 9- Mean BESS scores by stance (Mean \pm SD) for all conditions HCF, HC, and Ctrl.

BESS Score By Stance					
Variable	Condition	PRE	PRE	POST	POST
		(Mean SD)	95%CI	(Mean SD)	(95%CI)
BESS score: total (errors)	HCF	14.42 \pm 5.30	11.05 to 17.78	13.36 \pm 5.43	9.93 to 16.83
	HC	13.75 \pm 6.05	9.90 to 17.60	14.41 \pm 5.08	11.19 to 17.64
	Ctrl	15.00 \pm 6.33	10.98 to 19.02	18.96 \pm 8.46	13.58 to 24.33
BESS score: SL firm (errors)	HCF	2.04 \pm 1.41	1.15 to 2.93	2.46 \pm 1.47	1.53 to 3.39
	HC	2.33 \pm 1.47	1.40 to 3.27	4.04 \pm 2.97	2.16 to 5.93
	Ctrl	3.04 \pm 2.10	1.70 to 4.38	4.42 \pm 3.38	2.27 to 6.56
BESS score: Tan firm (errors)	HCF	0.46 \pm 0.49	0.14 to 0.77	0.58 \pm 0.73	0.11 to 1.05
	HC	0.29 \pm 0.39	0.04 to 0.54	0.88 \pm 0.98	0.25 to 1.49
	Ctrl	0.75 \pm 0.89	0.18 to 1.31	0.88 \pm 0.86	0.33 to 1.42
BESS score: SL foam (errors)	HCF	8.00 \pm 2.49	6.41 to 9.59	7.38 \pm 2.94	5.51 to 9.24
	HC	6.63 \pm 3.06	4.68 to 8.57	7.67 \pm 2.31	6.20 to 9.13
	Ctrl	7.38 \pm 3.46	5.18 to 9.57	8.79 \pm 2.33	7.31 to 10.27
BESS score: Tan foam (errors)	HCF	3.92 \pm 2.49	2.33 to 5.50	3.75 \pm 2.62	2.08 to 5.41
	HC	4.50 \pm 2.84	2.69 to 6.30	3.67 \pm 1.72	2.57 to 4.76
	Ctrl	4.21 \pm 2.49	2.62 to 5.79	4.17 \pm 2.71	3.25 to 5.08

HCF, hand cooling with fluid; HC, hand cooling; Ctrl, control; SL, single leg; Tan, tandem; Surface, firm and foam

Table 10- Calculated mean differences for BESS scores divided into separate parts of the test: single leg (SL) firm, Tandem (Tan) firm surface, single leg (SL) foam surface, Tandem (Tan) foam surface with 95% CI and ES. Hand cooling with fluid (HCF) vs. hand cooling (HC), hand cooling (HC) vs. control (Ctrl), hand cooling with fluid (HCF) vs. control (Ctrl). (‡) indicates strong effect size (0.8). Symbol (†) indicates moderate effect size (0.5). Symbol (*) indicates small effect size (0.2).

BESS Score Mean Difference and Effect Size By Stance					
Variable		PRE	PRE	POST	POST
		MD (95%CI)	ES	(MD; 95%CI)	ES
BESS score: total (errors)	HCF-HC	0.67 (-5.42 to 6.75)	0.12	-1.04 (-7.73 to 5.66)	0.20*
	HCF-Ctrl	-0.58 (-6.67 to 5.50)	0.20*	-5.58 (-12.28 to 1.11)	0.65†
	HC-Ctrl	-1.25 (-7.3 to 4.84)	0.10	-4.55 (-11.24 to 2.15)	0.79†
BESS score: SL firm (errors)	HCF-HC	-0.29 (-2.03 to 1.45)	0.20*	-1.58 (-4.39 to 1.23)	0.67†
	HCF-Ctrl	-1.00 (-2.74 to 0.74)	0.56†	-1.96 (-4.77 to 0.85)	0.75†
	HC-Ctrl	-0.71 (-2.45 to 1.03)	0.39*	-0.38 (-3.19 to 2.44)	0.12
BESS score: Tan firm (errors)	HCF-HC	0.17 (-0.48 to 0.82)	0.38*	-0.29 (-1.18 to 0.59)	0.35*
	HCF-Ctrl	-0.29 (-0.94 to 0.36)	0.40*	-0.29 (-1.18 to 0.59)	0.38*
	HC-Ctrl	-0.46 (-1.11 to 0.19)	0.66†	0.00 (-0.89 to 0.89)	0
BESS score: SL foam (errors)	HCF-HC	1.37 (-1.75 to 4.50)	0.49*	-0.29 (-2.91 to 2.33)	0.11
	HCF-Ctrl	0.63 (-2.50 to 3.75)	0.21*	-1.42 (-4.02 to 1.20)	0.53†
	HC-Ctrl	-0.75 (-3.87 to 2.37)	0.23*	-1.13 (-3.74 to 1.49)	0.48*
BESS score: Tan foam (errors)	HCF-HC	-0.58 (-3.27 to 2.11)	0.22*	0.08 (-2.70 to 2.87)	0.04
	HCF-Ctrl	-0.29 (-2.98 to 2.40)	0.12	1.33 (-4.11 to 1.45)	0.16
	HC-Ctrl	0.29 (-2.40 to 2.98)	0.11	-1.42 (-4.20 to 1.37)	0.22*

HCF, hand cooling with fluid; HC, hand cooling; Ctrl, control; SL, single leg; Tan, tandem; Surface, firm and foam

QuickBoard- Fast Feet drill

We did not observe any significant interactions between time points and conditions during the fast feet (FF) drill ($F_{2,22}=3.519$, $p = 0.074$). There were no significant differences ($p>0.05$) between groups for average FF drill touches from PRE to POST. However, percent change PRE to POST shows a $1.48 \pm 4.52\%$ improvement for HCF group, $3.53 \pm 5.61\%$ improvements for HC group, and a $2.29 \pm 8.31\%$ decline in the Ctrl group (Figure 31). This translates into a percent change from PRE to POST of [% change (95%CI), ES]; $3.77\%(-2.77, 10.31)$ 0.56 , $5.83\% (-0.71 \text{ to } 12.37)$ 0.82 and $-2.06\% (-8.60, 4.48)$ 0.40 change for HCF-Ctrl, HC-Ctrl and HCF-HC respectively (Table 8).

There were significant differences ($p \leq 0.008$) within groups for attempt 2 PRE to POST (Figure 32). There were significant reductions in mean FF count between attempt 1 and attempt 2 for Pre and Post measures in the HCF, HC, and Ctrl trials, p -values 0.006 , 0.007 , 0.002 respectively, p -values for POST

were 0.047, 0.001, and 0.000 respectively.

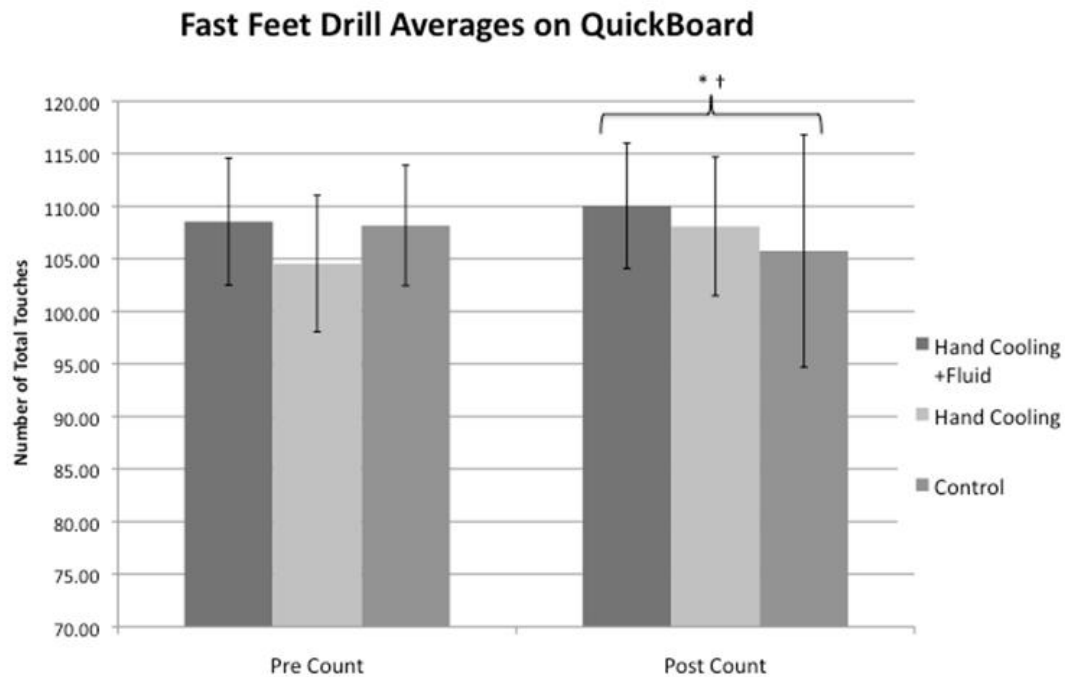


Figure 31- Number of touches in 30 seconds during the Quickboard Count Drill for PRE and POST for all conditions HCF, HC, Con. (*)= significant main effect for condition ($p=0.022$). (†) = significant group x time interaction ($p=0.014$)

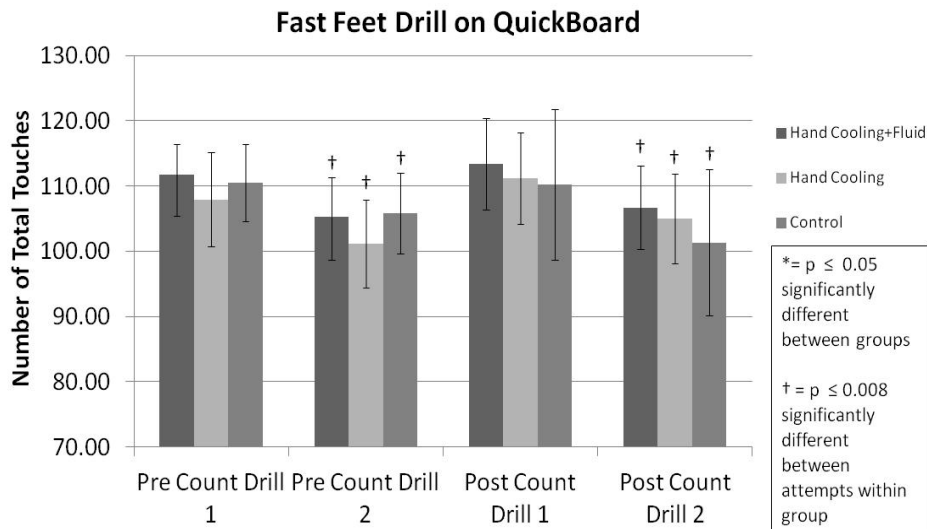


Figure 32- Fast Feet (FF) drill mean number of touches for both PRE and POST attempts #1 and #2 for all conditions HCF, HC, Con.

QuickBoard-REACT drill- We did not observe any significant interactions between time points and conditions during the REACT drill ($F_{2,22} = 2.733$, $p=0.087$). There were no significant differences between groups ($p>0.05$) PRE to POST for reaction time(s) (Figures 35 and 36). However, the % difference between [HCF-HC], [HCF-Ctrl] and [HC-Ctrl] were $3.51\% \pm 6.55$ faster, $3.60\% \pm 9.71$ slower and $2.45\% \pm 7.06$ slower respectively. The percent change in reaction time(s) from PRE to POST were [% change (CI), ES] 7.1% (-15.23 to 1.03), 0.86; 5.97% (-14.10 to 2.17), 0.88 and 1.14% (-6.99 to 9.27), 0.13 (Table 8).

There were no significant differences ($p>0.05$) between groups for accuracy percentage during the REACT drill (Figure 33 and 34).

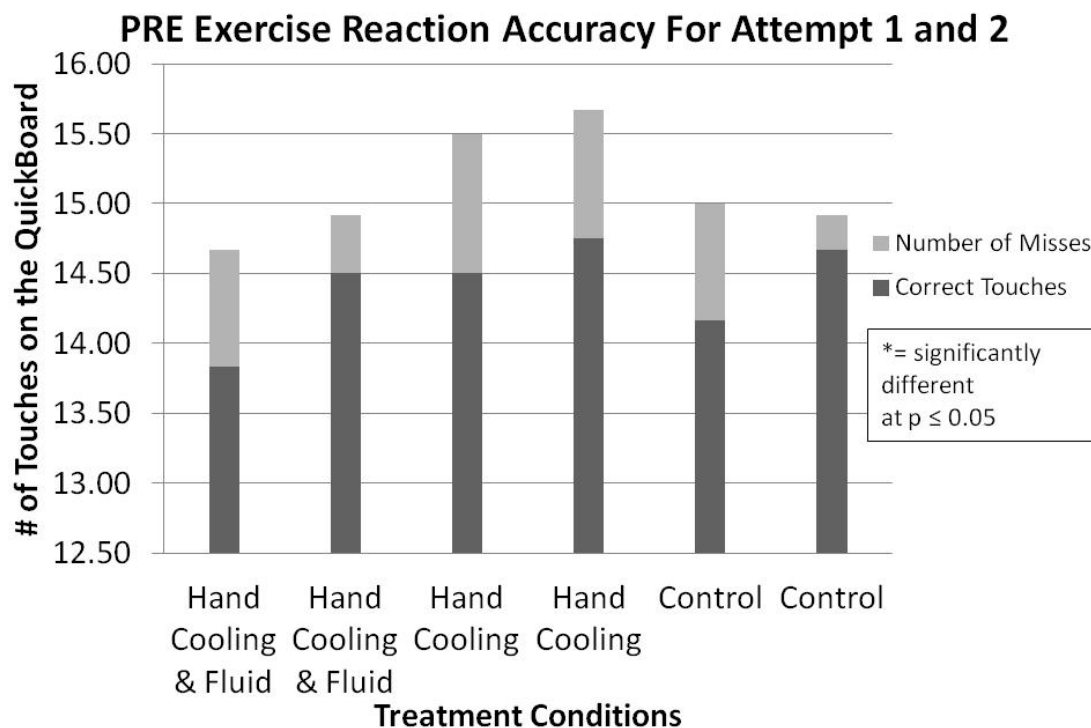


Figure 33- Mean pre exercise (PRE) reaction drill (REACT) accuracy measures for all conditions hand cooling and fluid (HCF), hand cooling (HC) and control (Ctrl). The total number of touches on the QuickBoard is divided into number of misses and correct touches. There are no significant differences between groups or within groups between attempts.

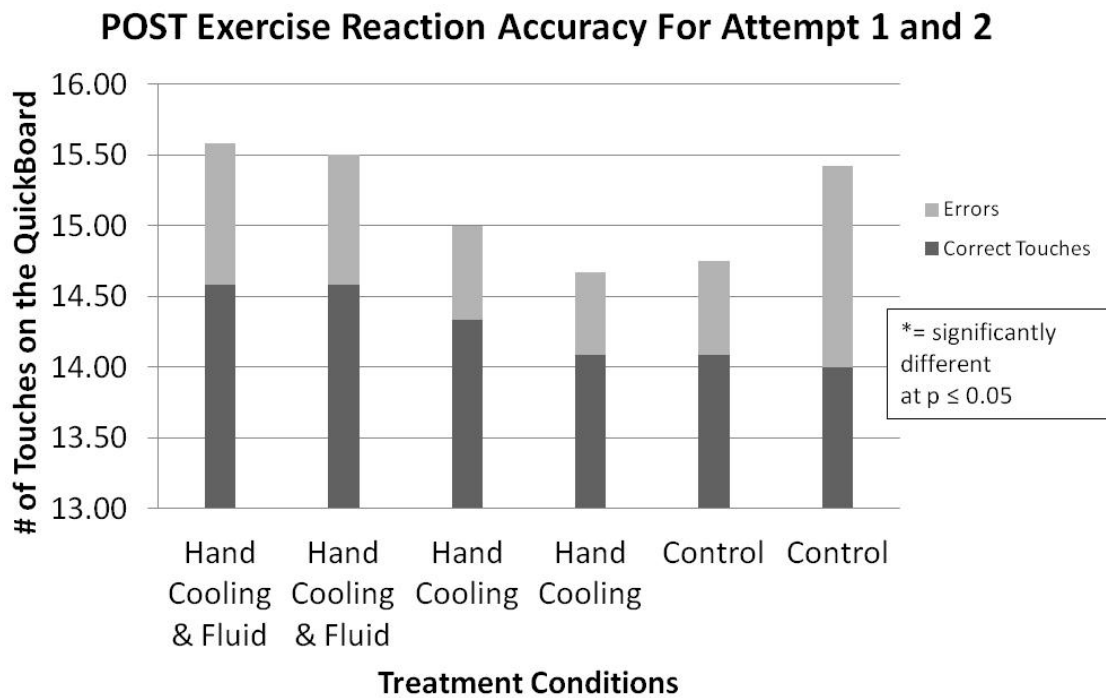


Figure 34- Mean post exercise (POST) reaction drill (REACT) accuracy measures for all conditions hand cooling and fluid (HCF), hand cooling (HC) and control (Ctrl). The total number of touches on the QuickBoard is divided into number of misses and correct touches. There are no significant differences between groups or within groups between attempts

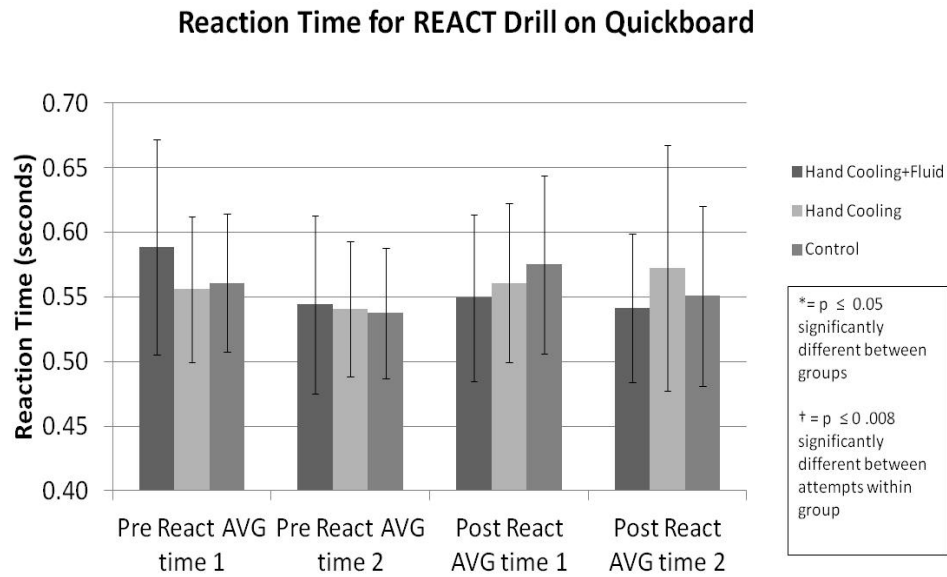


Figure 35- Mean reaction time during react drill (REACT) for PRE and POST attempts #1 and #2 for all conditions hand cooling and fluid (HCF), hand cooling (HC) and control(Ctrl).

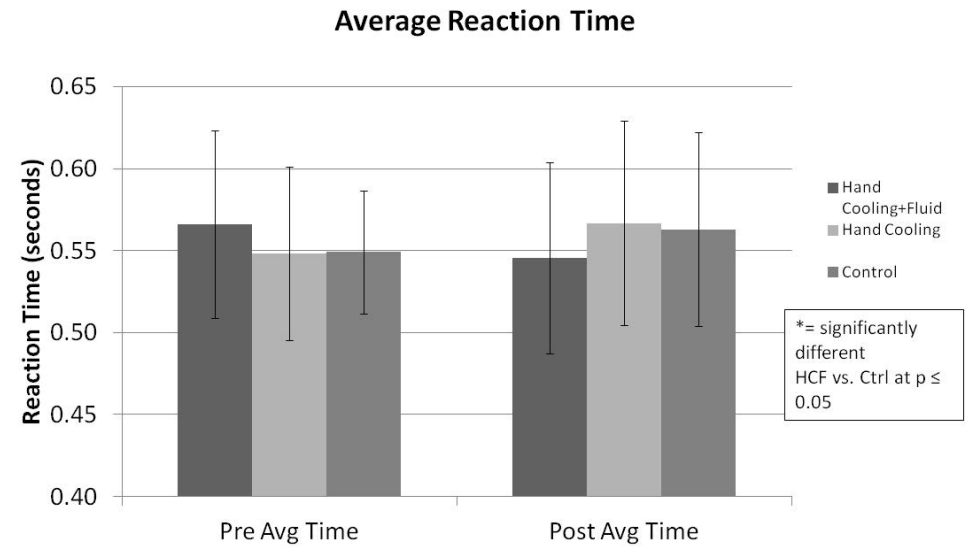


Figure 36- Average reaction times for react drill (REACT) during attempts #1 and #2 for PRE and POST for all conditions hand cooling and fluid (HCF), hand cooling (HC) and control(Ctrl).

Non-Motorized Treadmill Sprint- We observed a significant interaction between time points and conditions for the SPT speed ($F_{2,22} = 3.499$, $p = 0.048$) (Figure 38). PRE exercise NMT sprint had a mean of 15.77 ± 0.71 , 15.70 ± 0.50 , 16.07 ± 0.57 for HCF, HC and Ctrl respectively (Table 6). However, POST exercise attempt 1 was significantly faster ($p = 0.006$) than attempt 2 for the HCF group whereas the HC and Ctrl groups showed no significant change in speed from attempt 1 to attempt 2 p -values = 0.823 and 0.767 respectively.

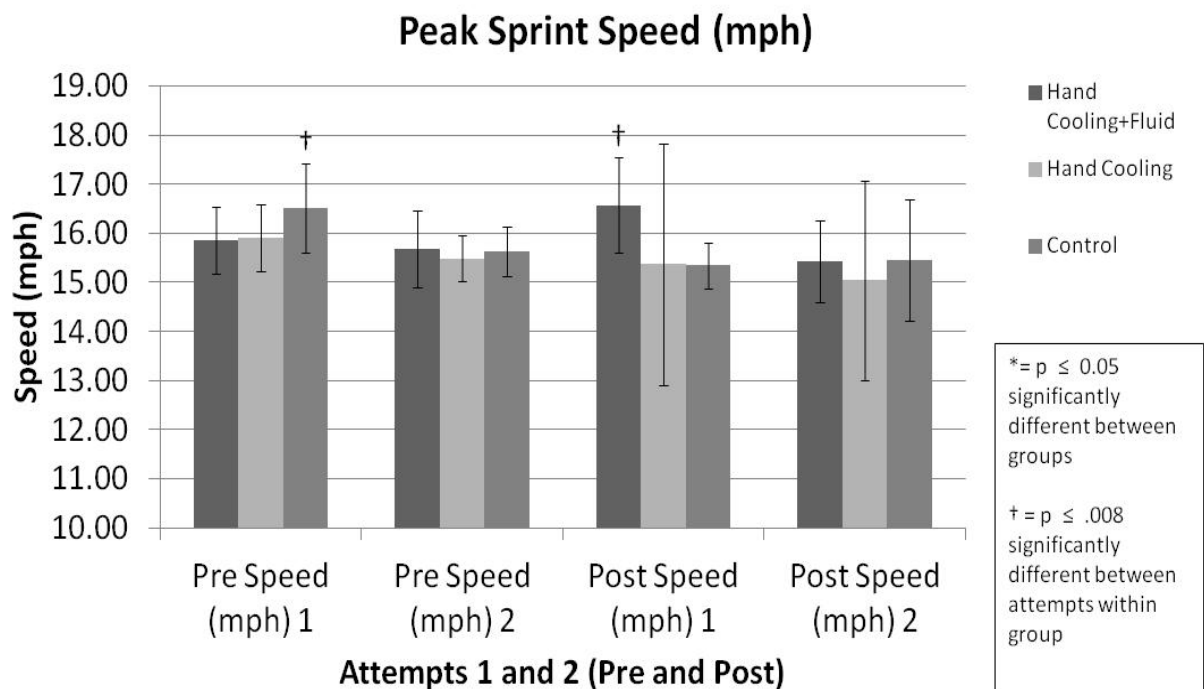


Figure 37- Peak sprint speeds for PRE and POST attempts #1 and #2 for all conditions HCF, HC, Con.

When the two attempts were averaged for pre and post sprint speed there were no significant changes ($p > 0.05$) from pre to post between groups and mean differences between groups ([HCF-HC], [HCF-Ctrl], [HC-Ctrl]) with p-values of 0.892, 0.053 and 0.479 respectively. The percent change scores in average PRE and POST speeds indicate a $1.43\% \pm 2.40$ improvement for the HCF group, a $0.68\% \pm 7.45$ decrement in the HC group and a $3.56\% \pm 3.29$ decrement in the Ctrl (Table 8).

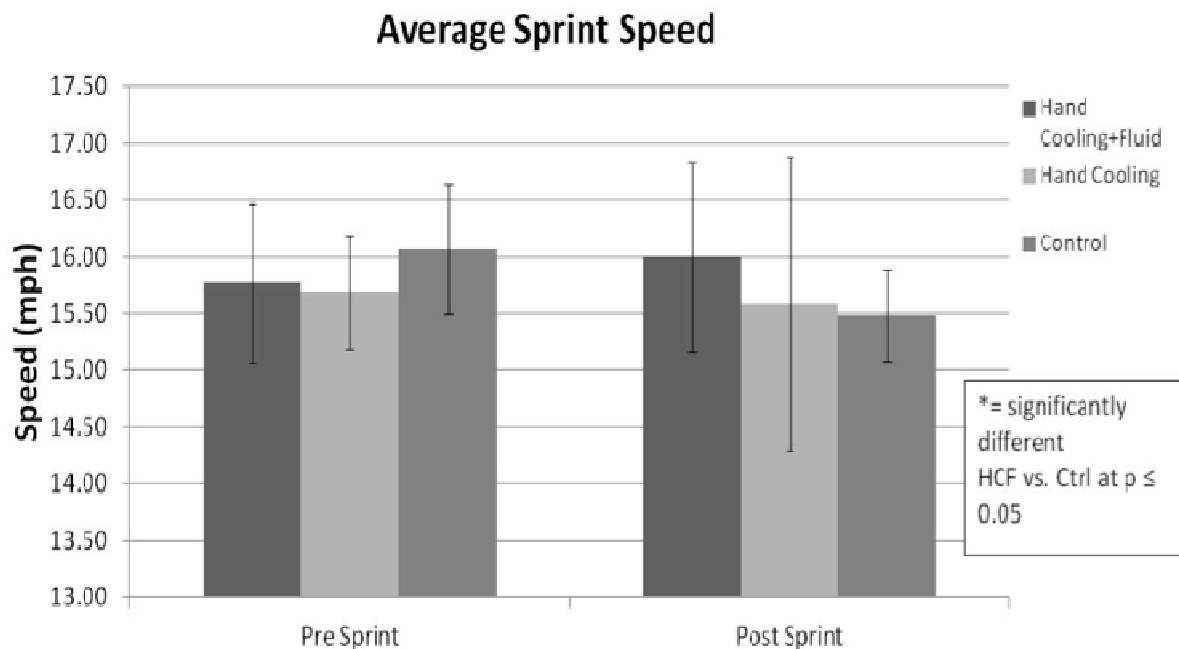


Figure 38- Average sprint speed of attempts #1 and #2 for PRE and POST for all conditions HCF, HC, Con. % difference between PRE and POST for HCF, HC, Con are 1.43% faster, 0.68% slower and 3.56% slower respectively.

Perceptuals

Ratings of Perceived Exertion Scale- No significant differences ($p > 0.005$) were found with rate of perceived exertion (RPE) scores between groups (Figure 39). However there were moderate to strong effect sizes at minute 87 for HCF-HC and HCF-Ctrl with mean differences of [MD (95%CI), ES] -2.50 (-5.49, 0.49), 0.87 and -2.25 (-5.24, 0.74), 0.73 respectively (Table 11).

Table 11- Mean difference for rate of perceived exertion (RPE) during all time points for all groups' hand cooling and fluid (HCF), hand cooling (HC), control (Ctrl). (‡) indicates strong effect size (0.8). Symbol (†) indicates moderate effect size (0.5). Symbol (*) indicates small effect size (0.2).

RPE Mean Difference \pm (95%CI) & Effect Size								
Condition	Pre	ES	12 min	ES	27 min	ES	42 min	ES
HCF-HC	0.75 (-0.66, 2.16)	0.57†	-1.08 (-3.28, 1.12)	0.5†	-0.33 (-2.84, 2.17)	0.13	-0.92 (-3.5, 1.67)	0.35*
HC-Ctrl	-0.42 (-1.8, 0.99)	0.40*	0.92 (-1.28, 3.12)	0.46*	0.17 (-2.34, 2.67)	0.08	0.58 (-2.00, 3.17)	0.26*
HCF-Ctrl	0.33 (-1.07, 1.74)	0.20*	-0.17 (-2.37, 2.03)	0.07	-0.17 (-2.67, 2.34)	0.06	-0.33 (-2.92, 2.25)	0.13
Condition	57min	ES	72 min	ES	87 min	ES	Post	ES
HCF-HC	-1.17 (-3.76, 1.43)	0.45*	-1.75 (-4.37, 0.87)	0.7†	-2.50 (-5.49, 0.49)	0.87‡	-1.42 (-4.98, 2.15)	0.42*
HC-Ctrl	0.33 (-2.26, 2.93)	0.14	0.17 (-2.46, 2.79)	0.07	0.25 (-2.74, 3.24)	0.09	0.08 (-3.48, 3.65)	0.02
HCF-Ctrl	-0.83 (-3.43, 1.76)	0.33*	-1.58 (-4.21, 1.04)	0.6†	-2.25 (-5.24, 0.74)	0.73†	-1.33 (-4.90, 2.23)	0.41*

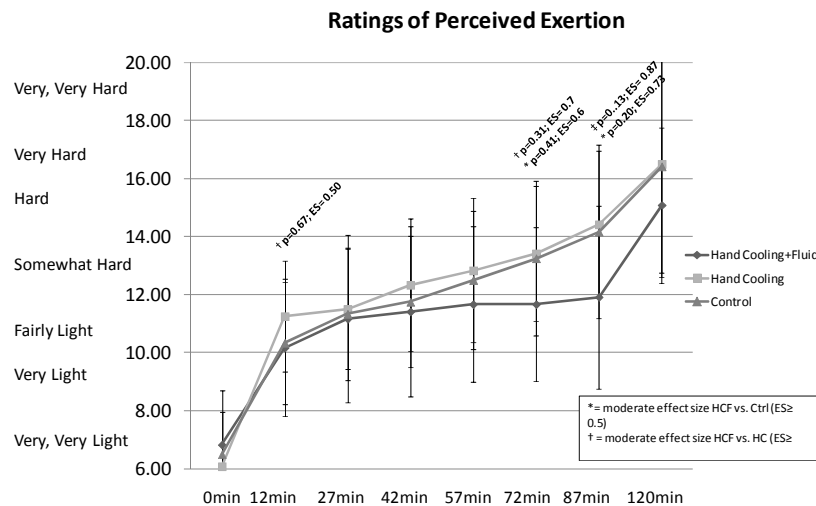


Figure 39- Mean values of rating of perceived exertion (RPE) at the end of each 6 bouts of treadmill exercise. No significant differences ($p \leq 0.005$) between groups HCF, HC, Ctrl.

Thirst Scale- There were significantly lower thirst sensation ($p \leq 0.05$) in the HCF group compared to HC and Ctrl groups starting at min 42 (Table 12). There were no significant differences ($p > 0.05$) in thirst perception for HC-Ctrl (Figure 40).

Table 12- Mean difference for thirst during all time points for all groups' hand cooling and fluid (HCF), hand cooling (HC), control (Ctrl). (‡) indicates strong effect size (0.8). Symbol (†) indicates moderate effect size (0.5). Symbol (*) indicates small effect size (0.2). (**) indicates significantly different (** $p = 0.05$ for HCF-HC and HCF-Ctrl)

Thirst Mean Difference \pm (95%CI) & Effect Size								
Condition	Pre	ES	12 min	ES	27 min	ES	42 min	ES
HCF-HC	0.33 (-0.72, 1.38)	0.30*	-1.08 (-2.37, 0.20)	1.02‡	-1.58 (-3.19, 0.03)	0.98‡	-3.08 (-4.66, -1.51)	** 2.52‡
HC-Ctrl	-0.17 (-1.22, 0.88)	0.22*	0 (-1.28, 1.29)	0	0.17 (-1.78, 1.44)	1.28‡	0.33 (-1.25, 1.91)	0.19
HCF-Ctrl	0.17 (-0.88, 1.22)	0.14	-1.08 (-2.37, 0.20)	0.74†	-1.75 (-3.36, -0.14)	** 0.24*	-2.75 (-4.33, -1.17)	** 1.80‡
Condition	57min	ES	72min	ES	87 min	ES	Post	ES
HCF-HC	-3.58 (-5.21, -1.95)	** 2.66‡	-4.25 (-5.92, -2.59)	** 3.3‡	-4.83 (-6.63, -3.04)	** 3.03‡	-4.25 (-5.87, -2.63)	** 2.78‡
HC-Ctrl	0.17 (-1.46, 1.80)	0.09	0.25 (-1.42, 1.92)	0.13	0.67 (-1.13, 2.46)	0.37*	0.67 (-0.96, 2.29)	0.45*
HCF-Ctrl	-3.42 (-5.05, -1.79)	** 2.23‡	-4.00 (-5.67, -2.34)	** 2.44‡	-4.17 (-5.96, -2.37)	** 2.32‡	-3.58 (-5.21, -1.96)	** 1.8‡

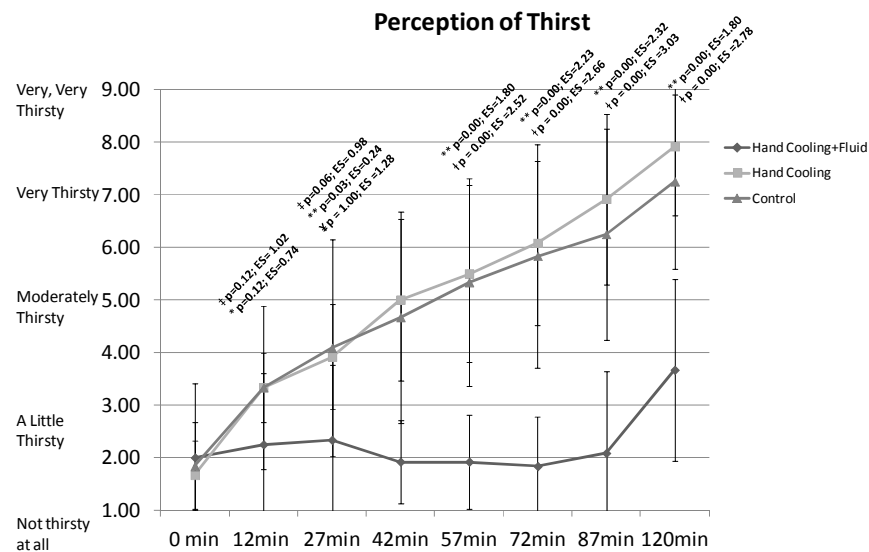


Figure 40- Mean values of rating of perceived exertion (RPE) at the end of each 6 bouts of treadmill exercise. No significant differences ($p \leq 0.005$) between groups HCF, HC, Ctrl. Symbol (*) indicates moderate effect size HCF vs. Ctrl ($ES \geq 0.5$). Symbol (†) indicates moderate effect size HCF vs. HC ($ES \geq 0.5$). Symbol (‡) indicates strong effect size HCF vs. HC ($ES \geq 0.8$). Symbol (¥) = strong effect size HC vs. Ctrl ($ES \geq 0.8$). Symbol (**) indicates significantly different HCF vs. Ctrl at ($p \leq 0.05$). Symbol (□) indicates significantly different HCF vs. HC ($p \leq 0.05$).

Thermal Scale- It was only at min 87 where HCF had a significantly lower ($p=0.03$) thermal perception than HC (Table 13 and Figure 41).

Table 13- Mean difference for thermal perception during all time points between hand cooling and fluid (HCF), hand cooling (HC), control (Ctrl). (‡) indicates strong effect size (0.8). Symbol (†) indicates moderate effect size (0.5). Symbol (*) indicates small effect size (0.2).

Thermal Mean Difference \pm (95%CI) & Effect Size								
Condition	Pre	ES	12 min	ES	27 min	ES	42 min	ES
HCF-HC	0.46 (-0.04, 0.95)	0.86‡	0.13 (-0.34, 0.59)	0.31*	0.17 (-0.48, 0.81)	0.26*	0.04 (-0.62, 0.70)	0.07
HC-Ctrl	-0.42 (-0.91, 0.08)	0.93‡	-0.25 (-0.71, 0.21)	0.55†	-0.29 (-0.94, 0.36)	0.49*	-0.17 (-0.83, 0.49)	0.23*
HCF-Ctrl	0.04 (-0.45, 0.54)	0.09	-0.13 (-0.59, 0.34)	0.26*	-0.13 (-0.77, 0.52)	0.19	-0.13 (-0.79, 0.54)	0.21*
Condition	57min	ES	72 min	ES	87 min	ES	Post	ES
HCF-HC	-0.08 (-0.87, 0.71)	0.12	-0.33 (-1.27, 0.60)	0.5†	-0.79 (-1.52, -0.06)	** 1.09‡	-0.63 (-1.57, 0.32)	0.60†
HC-Ctrl	0.04 (-0.75, 0.83)	0.05	0.33 (-0.60, 1.27)	0.32*	0.13 (-0.61, 0.86)	0.19	0.67 (-0.95, 0.95)	0.00
HCF-Ctrl	-0.04 (-0.83, 0.75)	0.05	0.00 (-0.94, 0.94)	0	-0.67 (-1.40, 0.06)	0.91‡	-0.63 (-1.58, 0.32)	0.65†

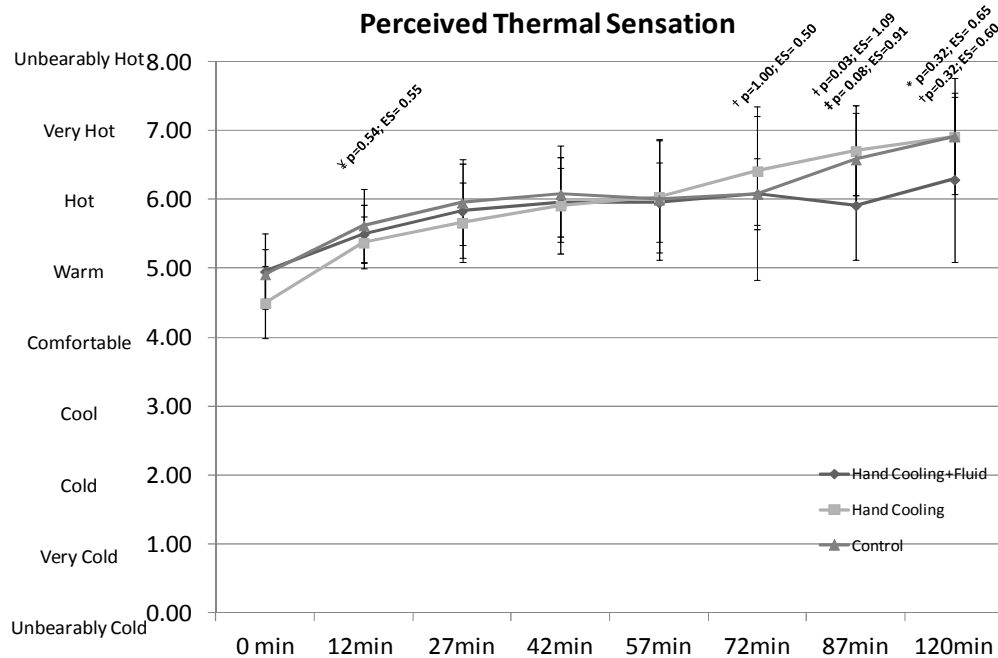


Figure 41- Mean values of thermal perception at the end of 6 bouts of treadmill exercise. Symbol (*) indicates moderate effect size HCF vs. Ctrl ($ES \geq 0.5$). Symbol (†) indicates moderate effect size HCF vs. HC ($ES \geq 0.5$). Symbol (‡) indicates strong effect size HCF vs. HC ($ES \geq 0.8$). Symbol (¥) = strong effect size HC vs. Ctrl ($ES \geq 0.8$). Symbol (**) indicates significantly different HCF vs. Ctrl at ($p \leq 0.05$). Symbol (‡) indicates significantly different HCF vs. HC ($p \leq 0.05$).

Fatigue Scale- There were no significant differences ($p>0.05$) between groups in perception of fatigue during exercise (Figure 42). A moderate ES (0.52) and strong ES (0.82) were found during min 87 and POST respectively for HCF-HC and a moderate ES (0.52) was seen during POST for HCF-Ctrl (Table 14).

Table 14- Mean difference for fatigue perception during all time points for all groups' hand cooling and fluid (HCF), hand cooling (HC), control (Ctrl). (‡) indicates strong effect size (0.8). Symbol (†) indicates moderate effect size (0.5). Symbol (*) indicates small effect size (0.2).

Fatigue Mean Difference \pm (95%CI) & Effect Size									
Condition	Pre	ES	12 min	ES	27 min	ES	42 min	ES	
HCF-HC	0.25 (-0.50, 1.00)	0.30*	0.08 (-1.30, 1.47)	0.06	0.08 (-2.08, 2.25)	0.04	-0.58 (-2.62, 1.46)	0.29*	
HC-Ctrl	0.25 (-0.50, 1.00)	0.40*	0.08 (-1.30, 1.47)	0.07	0.08 (-2.08, 2.25)	0.04	0.50 (-1.54, 2.54)	0.24*	
HCF-Ctrl	0.50 (-0.25, 1.25)	0.73†	0.17 (-1.22, 1.55)	0.12	0.17 (-2.00, 2.33)	0.07	-0.08 (-2.12, 1.96)	0.04	
Condition	57min	ES	72 min	ES	87 min	ES	Post	ES	
HCF-HC	-1.00 (-3.49, 1.49)	0.42*	-1.08 (-3.70, 1.54)	0.44*	-1.25 (-3.83, 1.33)	0.52†	-1.92 (-4.52, 0.68)	0.82‡	
HC-Ctrl	0.75 (-1.74, 3.24)	0.30*	0.33 (-2.29, 2.95)	0.12	0.50 (-2.08, 3.08)	0.19	0.50 (-2.10, 3.10)	0.20*	
HCF-Ctrl	-0.25 (-2.74, 2.24)	0.11	-0.75 (-3.37, 1.87)	0.30*	-0.75 (-3.33, 1.83)	0.31*	-1.42 (-4.02, 1.18)	0.52†	

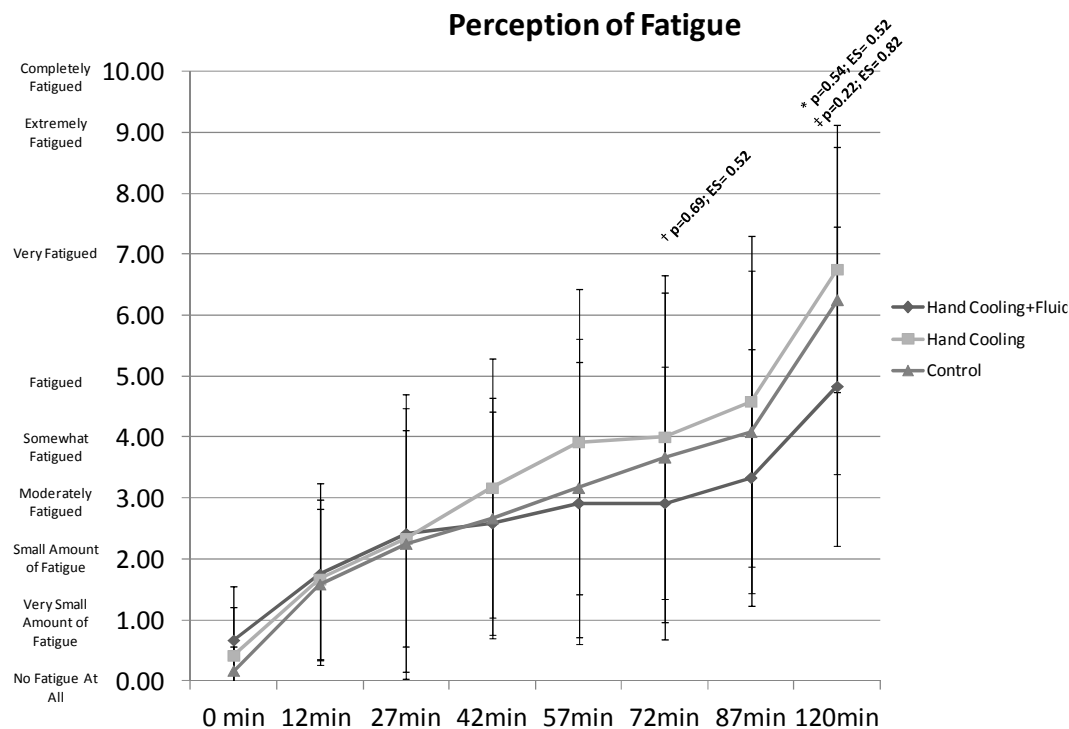


Figure 42- Mean values of fatigue perception at the end of 6 bouts of treadmill exercise. Symbol (*) indicates moderate effect size HCF vs. Ctrl ($ES \geq 0.5$). Symbol (†) indicates moderate effect size HCF vs. HC ($ES \geq 0.5$). Symbol (‡) indicates strong effect size HCF vs. Ctrl ($ES \geq 0.8$).

Pain Scale- There were no significant differences ($p>0.05$) between groups in perception of pain during exercise (Figure 43). The ES for HCF-HC were moderate 0.50, 0.60, 0.52, and 0.61 during time points 57, 72, 87 and POST respectively. The ES for HCF-Ctrl were moderate 0.56, 0.70, and 0.58 during time points 42, 57, 72 respectively. Strong ES were found during time points 87 and POST with values of 0.80 and 0.89 respectively (Table 15).

Table 15- Mean difference in pain perception for HCF-HC, HC-Ctrl and HCF-Ctrl from PRE and POST. (‡) indicates strong effect size (0.8). Symbol (†) indicates moderate effect size (0.5). Symbol (*) indicates small effect size (0.2).

Pain Mean Difference \pm (95%CI) & Effect Size								
Condition	Pre	ES	12 min	ES	27 min	ES	42 min	ES
HCF-HC	0.04 (-0.28, 0.36)	0.13	-0.29 (-0.96, 0.38)	0.41*	-0.25 (-0.93, 0.43)	0.35*	-0.33 (-1.14, 0.47)	0.47*
HC-Ctrl	0.04 (-0.28, 0.36)	0.14	0.13 (-0.55, 0.80)	0.18	0.13 (-0.56, 0.81)	0.18	-0.08 (-0.89, 0.72)	0.10
HCF-Ctrl	0.08 (-0.24, 0.40)	0.27*	-0.17 (-0.84, 0.51)	0.30*	-0.13 (-0.81, 0.56)	0.23*	-0.42 (-1.22, 0.39)	0.56†
Condition	57min	ES	72 min	ES	87 min	ES	Post	ES
HCF-HC	-0.38 (-1.22, 0.47)	0.50†	-0.50 (-1.40, 0.40)	0.60†	-0.42 (-1.29, 0.45)	0.52†	-0.63 (-1.89, 0.64)	0.61†
HC-Ctrl	-0.17 (-1.02, 0.68)	0.18	0.04 (-0.86, 0.44)	0.04	-0.21 (-1.08, 0.66)	0.22*	-0.46 (-1.73, 0.81)	0.32*
HCF-Ctrl	-0.54 (-1.39, 0.31)	0.70†	-0.46 (-1.36, 0.94)	0.58†	-0.63 (-1.49, 0.24)	0.80‡	-1.08 (-2.35, 0.19)	0.89‡

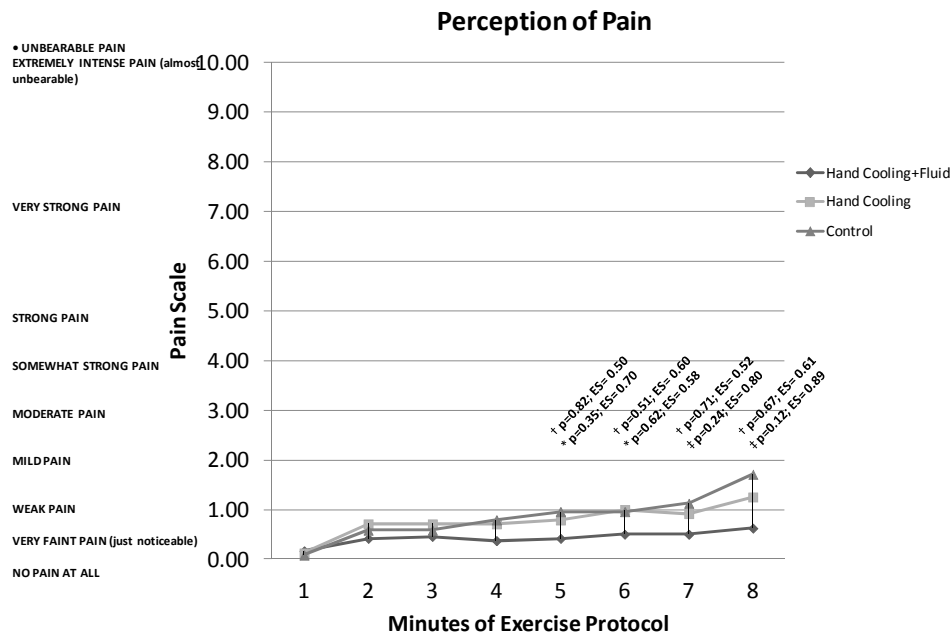


Figure 43- Mean values of pain perception at the end of 6 bouts of treadmill exercise. Symbol (*) indicates moderate effect size HCF vs. Ctrl ($ES \geq 0.5$). Symbol (†) indicates moderate effect size HCF vs. HC ($ES \geq 0.5$). Symbol (‡) indicates strong effect size HCF vs. Ctrl ($ES \geq 0.8$).

Environmental Symptoms Questionnaire Scale- HCF was significantly lower than HC and Ctrl (p=0.001 and p=0.002 respectively) during POST measurement of the environmental symptoms questionnaire (Table 16).

Table 16- Mean difference in ESQ with HCF-HC, HC-Ctrl and HCF-Ctrl for PRE and POST. (‡) indicates strong effect size (0.8). Symbol (†) indicates moderate effect size (0.5). Symbol (*) indicates small effect size (0.2).

ESQ Mean Difference \pm (95%CI) & Effect Size

Condition	Pre	ES	Post	ES
HCF-HC	1.00 (-1.19, 3.19)	0.43*	-11.17 (-18.08, -4.26)	** 1.55‡
HC-Ctrl	-0.17 (-2.36, 2.02)	0.09	0.83 (-6.08, 7.74)	0.11
HCF-Ctrl	0.83 (-1.36, 3.02)	0.37*	-10.33 (-17.24, -3.43)	** 2.04‡

DISCUSSION

The purpose of this study was to investigate the effectiveness of the CoreControl™ hand cooling system as a treatment for reducing the associated symptoms on individuals exercising in a hot environment while wearing an American Football Uniform. A secondary aim was to examine if a reduction in heat stress via peripheral cooling of one hand would lead to an increase in football performance. In conjunction with previous studies^{87,88,91-94,97} we observed an attenuation in the rise of T_{RE} , reduction of HR, and subsequent improvements in performance particularly in the areas of balance, reaction, and sprint speed in the HCF group.

Rectal Body Temperature

It has already been shown that continuous extraction of heat from the body through one hand during exercise is an effective mode of attenuating the rise in T_{RE} and causes an increase in aerobic endurance⁸⁸ however, to our knowledge there has yet to be a study investigating the intermittent use of this device in an uncompensable heat stress situation while wearing a full American football uniform. Both the external heat stress (e.g. equipment and environmental conditions) and the internal heat stress (e.g. metabolic heat produced via exercise) produced during this experiment impaired the body's evaporative capacity, which is the primary thermoregulatory mechanism for heat loss. Previous studies^{88,89,97} have reported a significant cooling effect while utilizing the hand cooling device when wearing recreational clothing in less severe environmental conditions. Furthermore, Grahn et al.⁸⁸ reported that effectiveness of the CoreControl™ decreased in an exponential manner with increasing exercise intensity indicating that there is a point where metabolic heat production (e.g. high intensity exercise) exceeds the ability to extract heat from the body. In our study, all groups received similar treatment and worked at similar intensities as these previously mentioned studies,^{88,89,97} and while our HC group responded similarly to these past studies, the HCF treatment group responded more favorably to the hand cooling treatment. A potential explanation for this reduction in the POST HCF T_{RE} response starting after the 66th minute of exercise (Figure 23) may have been due to the additional fluid received by the HCF group. It is theorized that the fluid replacement minimized blood volume reduction during exercise. This maintenance of adequate blood volume allowed exercising muscles to perform the activity as well as the skin to remove the heat via evaporation allowing for the observed response. If this theory were true, this would provide further substantial evidence for the current body of research suggesting that fluid losses be minimized to <2.0% during exercise. In the current investigation the %BML of the HCF group of 1.5% was significantly less compared to the HC=3.08% ($p=0.00$) and Ctrl=3.29% ($p=0.00$).

Unfortunately in this investigation we were unable to have a fluid only trial, however this research still suggests that the HC and fluid were additive in the reduction of T_{RE} during UCHS.

Glabrous skin surfaces allow for the effective removal of heat due to the large volume of blood stored in AVA's and the close relationship to the skins surface.^{79,112} Through the application of this external heat sink modality to the hand with fluid replacement, heat was removed via conduction from the body more effectively and thus mitigate the rise in T_{RE} and HR.^{79,91,92} Applying a hand cooling treatment does decrease the body's heat storage, and to gain a better understanding further examination of the heat balance equation is necessary. It is well documented that uncompensable heat stress implies that evaporative, convective, conductive and radiative mechanisms of heat loss are impeded. When a hand cooling modality is applied under these circumstances during uncompensable heat stress it is the only (-) value removing heat via conduction on the right side of the equation. Evaporation and convection are minimal due to the environmental temperature and humidity which is warmer and more saturated than the skin. Under these conditions minimal transfer is occurring. Furthermore the fluid replacement aided in the maintenance of blood volume which likely resulted in redistribution of blood to both the periphery and the exercising muscles.

To our knowledge this is the first study to investigate the additive influence of hand cooling with hydration on T_{RE} . Intermittent removal of heat from the body when combined with hydration to minimize fluid losses during exercise can prevent an individual from approaching dangerous core temperature levels that may lead to a medical emergency such as EHS. With hydration policies and recommendations being followed by many athletes,^{5,9} it stands to reason that understanding the additive effect hydration has on hand cooling is important for future research. The average mean difference (MD) in T_{RE} between HCF vs. Ctrl from minute 66 through the POST time point was 0.46°C (0.83°F). This reduction in T_{RE} is very important clinically when put into perspective. For example, when

the change in T_{RE} for each additional 1% body mass loss ($\Delta \cdot 1\%BML^{-1}$) is calculated out to 4 and 5% BML this would result in rates of increase that would be considered dangerously high for many medical professionals. (See Table 4)^{16,40,115,116} Essentially if you took the same individual and provided them with HCF during one trial and the control treatment in another trial, for each additional 1% BML they would reach 40.68°C (levels equal to exertional heat stroke) at 4%BML compared to the HCF individual only at 39.2°C (normal exercising body temperature).

Table 4- Projected Increase in body temperature (T_{RE}) for every 1% of BML during exercise. This was calculated based on the change in T_{RE} in each condition and was related to average % BML in the same condition. Then we extrapolated the measures to typical % BML experienced by exercising individuals. The red boxes denote those T_{RE} that have reached levels over 104°F, which is a sign of exertional heatstroke (EHI).

Projected Increase in Body Temperature °C (°F) For Every Additional 1% BML						
	0%	1%	2%	3%	4%	5%
HCF	37.6 (99.68)	38 (100.4)	38.4 (101.12)	38.8 (101.84)	39.2 (102.56)	39.6 (103.28)
HC	37.6 (99.68)	38.18 (100.72)	38.76 (101.77)	39.34 (102.81)	39.92 (103.86)	40.86 (105.5)
Ctrl	37.6 (99.68)	38.37 (101.06)	39.14 (102.45)	39.91 (103.84)	40.68 (105.22)	41.45 (106.61)

Cardiovascular Responses

This investigation enabled the researchers to examine the relationship between T_{RE} and CV strain. Since hand cooling treatments were delivered intermittently throughout exercise, we were able to examine the effect of HCF and HC on HR over time (Figure 25). As we expected the HCF group experienced a $10 \text{ b} \cdot \text{min}^{-1}$ reduction in HR compared to the HC and Ctrl groups for almost 30 minutes of exercise from minute 57-87. The reduction in heart rate is likely due to the fluid replacement, which during exercise in the heat has been well documented to reduce the effects of cardiovascular drift.¹¹⁷ As a result of the fluid replacement, blood volume increase causing a subsequent increase in stroke volume

which maintains a lower HR during exercise. HR in the HCF group was not significantly different, however upon the completion of exercise prior to performance tasks, an interaction was observed. The HC and Ctrl groups experienced a decrease in HR while the HCF groups HR experienced an increase (Figure 25). Those in the HCF group were able to give a greater effort at a higher intensity when asked to perform the agility, reaction, and sprint task specifically. For example in the SPT task a significant reduction ($p=0.006$) in speed from attempt 1 (16.57 ± 0.97) to attempt 2 (15.43 ± 0.83) POST was observed within the HCF group. This indicates that the reduction in HR from the HC and the fluid during the 90 minute exercise protocol enabled the HCF group to perform at a higher intensity and thus produced a faster speed than the HC and Ctrl groups. This is further substantiated by the equation for cardiac output $Q = HR \times SV$. During dehydration exercise, in order for Q to be maintained, HR must increase as SV decreases. If the reduction in SV is minimized through fluid replacement, HR is reduced and the cardiovascular (CV) stress is decreased. This reduction in CV stress enables for a greater potential for maximal exercise intensity when called upon by the active muscles. In order to quantify work done by the cardiovascular system we can calculate training impulse (Avg. HR x Duration). The training impulse for the HCF group was (Mean \pm SD) 19167.0 ± 1751.0 total beats, while the HC and Ctrl groups were 19813.0 ± 1599.0 and 19921.0 ± 1381.0 total beats respectively. Although not significant ($p>0.05$) the MD (95%CI; ES) for HCF-Ctrl= -754 total beats (-2385, 877; 0.48).

Another interesting point gained from this study was determined when the change in HR for every 1% BML was determined. $\Delta \cdot 1\%BML^{-1}$ for [HCF-HC] and [HCF-Ctrl] was -6 ± 10 bpm and -7 ± 8 bpm for every 1% respectively. This indicates that there was a slight difference in heart rate between HC and Ctrl when fluid is accounted for. The findings from this study are similar to the findings presented by Adams et al. who examined the $\Delta \cdot 1\%BML^{-1}$ in a meta-analysis examining hyperthermic individuals.

Performance Battery

Previous studies have shown the ability to maintain increased cardiovascular performance when peripheral cooling is used in hot environments.⁸⁸ In the absence of cooling Hargreaves et al.¹¹⁷ described a state of "circulatory conflict" that arises between skin and active muscle, ultimately leading to a reduction of blood flow to muscle in order to maintain proper thermoregulation. Many studies have investigated this aspect of performance using hot and humid environmental conditions, inhibitory garments and various cooling treatments, however very few have looked at high intensity and short duration activity after peripheral cooling. Grahn et al.⁸⁷ showed that by maintaining the optimal temperature for muscle activity by hand cooling, work and strength during pull-up and bench press exercises increase. We found similar improvements in performance with improvement of sprint speed, increased reaction time, increased foot speed and improved balance and proprioception

The sport specific performance variables used in this study are the first to be implemented in a cooling study. So, it was difficult to compare our results to previous literature. However there is a vast knowledge available on ergogenic aids used in sport such as supplements and specified garments.

Our measurements of lower extremity power utilizing a CMVJ found that there were no significant differences in VGRF between groups. However, for jump height there was a significant condition x time interaction, with each of the conditions increasing from PRE to POST. We can infer that this interaction occurred due to a warm-up effect after executing the treadmill protocol. The PRE CMVJ was the first task to be completed once acclimatized to the heat chamber for all three testing trials. Conversely the POST CMVJ was the first task completed after "warming-up" by walking on the treadmill for 90 minutes. At this point muscles would have reached an optimal temperature for power and strength output. Similar to previous studies, it may have been due to this "active warm-up" that caused an increase in CMVJ height.¹¹⁸

In the current investigation although no significant differences were observed from PRE to POST for any of the stances BESS Total, SL Firm, SL Foam, Tan Firm, or Tan Foam there was an observed increase in the percentage of errors within group for the Ctrl condition. Ctrl experienced 30.13% more errors following the 90 minute exercise while the HCF group experienced only 7.17% more errors. Although the trial conditions were slightly different, the results from the present study demonstrated that post exercise errors were higher for the HCF group (13.36 ± 5.43), HC group (14.41 ± 5.08) and Ctrl group (18.96 ± 8.46) when compared to the findings of Distefano et al.⁵⁹ Distefano et al. found hypohydrated hot (HYH) and euhydrated hot (EUH) individuals while wearing a military pack had BESS scores of 10.83 ± 3.56 and 10.00 ± 2.70 total errors, respectively.⁵⁹ Interestingly, although %BML in the current study (HCF= $1.60 \pm 0.53\%$) was similar to Distefano et al. (EUH= $1.3 \pm 0.9\%$) the errors observed in the Ctrl were much greater even though %BML for HYH was $5.7 \pm 1.6\%$ compared to the Ctrl in our study ($3.29 \pm 0.68\%$). It is unlikely that the increased errors are explained by the differences in T_{RE} given that POST T_{RE} was similar between the studies. T_{RE} only differed (MD = Current study minus Distefano et al.) 0.29°C in the hydrated trials and -0.09°C in the dehydrated trials. The observed increase in errors may have been a result of the difference in equipment worn in the two trials. The football equipment load distribution is higher with most of the weight being in the helmet and shoulder pads whereas the military pack distributes the load to the hips and lower back resulting in a lower the center of gravity which may possibly improve balance during the BESS compared to the football uniform.

Agility and change-in-direction movements allow players to evade and gain ground when going head-to-head with an opponent.¹¹⁹ The goal of the offensive player is to cause uncertainty and cause the defensive player to speculate and then evade and outrun them¹¹⁹ while the defender must react to cues to 1) evade offensive blocks and 2) provide enough force through the opponent to bring them to the ground. One can see that foot speed and reaction time play a large part in the activities football players execute on the field. Using these statements as a basis to compare to, our study showed a slight

improvement in foot speed with a 1.48% increase and 3.58% increase from PRE to POST for HCF and HC groups respectively. With an overall improvement for HCF and HC group over the control group of 3.77% and 5.82% respectively we can apply that to a practical scenario where individuals in the former group would have an increased ability to make a change-in-direction movement and then evade their opponent in this scenario (Ctrl group). This brings into account having the blood flow and blood volume to active muscles to provide the oxygen and nutrients needed for anaerobic high intensity movements. Having the energy stores and ability to gain ground on an opponent is only a piece of one's agility performance.

Reaction time takes into account the brains ability to interpret and signal to active body parts providing an increased awareness and control during movement. In conjunction with foot speed improvements, the HCF group had 3.5% faster reaction times from PRE to POST exercise. This translates into a 5.95% improvement over the control group, which leads us to believe that by decreasing the perceived exertion, reducing thermal and thirst sensation it allows individuals to not only move faster, but also react to visual stimulus. This spans from the realm of performance increase to also safety during play, especially toward the end of a practice or game in an uncompensable heat stress situation. As reaction time decreases from a view of fatigue and body positioning it could possibly lead to an increased risk of serious injury.

In the current investigation although no significant differences were observed from PRE to POST during the SPT task, there was an observed percent increase in performance within group for the HCF condition compared to HC and Ctrl conditions. HCF group was able to perform significantly better in POST attempt #1 vs. attempt #2 ($p=0.006$), whereas both HC and Ctrl had mean peak sprint speeds that remained relatively close. This was possibly due to the attenuation of the rise in HR during the exercise session of an avg. of $10 \text{ b} \cdot \text{min}^{-1}$ lower in the HCF condition compare to HC and Ctrl.

The HCF group ran at peak sprint speeds that were 1.43% faster following the 90 minute exercise. Both HC and Ctrl were slower after exercise with a decrease in speed by 0.68% and 3.56% respectively. With a performance increase of 4.99% (HCF-Ctrl) our study falls in line with others that have found anywhere from 1.1% to 17% improvements in endurance running after receiving body cooling.¹²⁰⁻¹²² The improvements found after cooling parallels those seen from the ergogenic aids such as caffeine, and correlate to a major advantage in the practical setting of a race or game.¹²³ Kay et al. found that only small decreases in T_{SKIN} and T_{RE} are necessary for improved performance.¹²² In contrast our study showed significant attenuation in T_{RE} (HCF-Ctrl) and although the methodology was different the performance increase was only 1.1% less than the biking performance increase they found.

When applied to football specific performance assessment a 4.99% advantage could equate to the difference in reaching the status of an elite level professional athlete. An approximate 5% advantage while running a 40 yard dash is the difference in a 5.45 and 5.19 second trial for an individual running at 15 mph ($7.33 \text{ yards} \cdot \text{sec}^{-1}$). Sierer et al. found that the difference between a drafted and undrafted (4.49 ± 0.09 seconds, 5.59 ± 0.11 seconds) skill position player 40-yard dash time was 0.10s, a 21% difference.¹²⁴

Perceptuals

During the 90 minute treadmill exercise perceived exertion remained similar between HC and Ctrl conditions. Although not significant, it was noted that the HCF condition plateaued at minute 27 and at the end of treadmill exercise minute 87, there was a strong effect size between HCF-HC ($ES=0.87$). We can speculate that a lower HR from minute 57-87 in the HCF condition causes a decrease in perception of exertion.

With the HCF group receiving fluids in an attempt to minimize %BML during the testing session we expected to see a significant difference ($p \leq 0.005$) in perception of thirst. This was confirmed starting

at minute 27 and continuing on until the POST for HCF-Ctrl and minute 42 to POST for HCF-HC (Figure 33). During the course of the 90 minute exercise session the HCF groups thirst perception remained constant and actually decreased at points, while both HC and Ctrl increased steadily during exercise. The fact that participants perceived less thirst in the HCF vs. HC and HCF vs. Ctrl trials and that HC vs Ctrl were closely related to each other corresponds to the USG measurements confirming that we achieved separate hydration statuses between groups.

Although our study found that T_{RE} remained lower from minute 66 to POST exercise for the HCF condition, thermal sensation, with the exception of minute 87 (significantly lower HCF vs. HC; $p=0.08$) showed little variation over time between groups. This finding was unexpected, however work from Candas et al. concluded that perception of heat stress is independent of T_{RE} , and thermal discomfort is more closely tied to sweating rate and skin wettedness.¹²⁵ Our study with individuals exercising under uncompensable heat stress, further emphasizes this theory. Although T_{RE} differed between groups, they all experienced heavy sweating and protective equipment saturated in sweat which is what we observed. Based on thermal sensation there were very minimal differences between groups throughout the 90 minutes of exercise (Figure 41).

In this investigation we found that although not significant ($p>0.05$) perception of fatigue by the participants in the HCF condition was less than both HC and Ctrl with moderate to large ES. HCF experienced reduced fatigue as indicated by the strong ES (HCF-HC=0.82) and moderate ES (HCF-Ctrl=0.52) at the POST time point, the theory behind this is the mitigation of CV drift in the HCF group during exercise.

The goal of this study design was to complete a treadmill exercise protocol as a tool to increase T_{RE} , and execute the performance battery utilizing full recovery periods for optimal performance (3:1 rest to work). Muscle and CV perception of pain was not intense to our participants because of the lack

of intense stress to the CV system and minimal muscle breakdown. Mean difference for perception of pain for the HCF-Ctrl at minute 87 and at the POST time point showed strong ES of 0.80 and 0.89. The HCF group's perception of pain plateaued while both HC and Ctrl groups increased. This is likely due to whole body muscle activation and the volume of anaerobic stress experienced in the short duration of POST performance battery.

POST HCF vs HC and HCF vs. Ctrl showed very large ES (HCF-HC= 1.55, HCF-Ctrl=2.44) for the severity of environmental symptoms. This mimicked the perception of thirst difference between groups in conjunction with T_{RE} and HR. When we see that ESQ and the perception of thirst are closely related, it stands to reason that the premises for these two variables are the same.

Methodological Considerations

A limitation of the methodology for treatment groups is that we did not include a hydration only condition. Although this would have given us a clear distinction between the effects of hydration and the effects of peripheral hand cooling, we feel that this does not negate the findings of this study. It is understood that hydration does improve performance in the way of power, strength, and both anaerobic and aerobic activity, so in conjunction with our findings it can be speculated that hand cooling is an additive effect. This synergistic effect can be of practical application to sports team since most already understand the importance of a hydration protocol.

An additional possible concern may be the power of our subject population. We were powered to see a change in core body temperature related to the three conditions of hand cooling only, hand cooling with fluid and control and not for the performance battery. Although data points were trending toward significance over time, the power of our sample affected our ability to see significant differences due to large standard deviations. This is why we looked at percent change from PRE to POST for the performance battery, and as far as practical application it allowed us to make important comparisons

and add to the body of knowledge for peripheral hand cooling's effect on performance. Large standard deviations were also seen for our HR data and this could be due to different relative intensities of the treadmill protocol between subjects. The methodology of this study was to keep intensity of exercise the same within subject for each of their 3 testing trials allowing them to reach T_{RE} of at least 39.0°C. Since everyone's tolerance to the heat is different the intensities of the treadmill protocol had to be different for each subject. So in order to adjust for this we used change in HR to make our comparisons.

Practical Applications

The purpose of this study was to evaluate the effectiveness of CoreControl™ on physiologic and performance measurements of individuals in the heat with football equipment. The subjects in this study were subjected to severe environmental conditions (34.94±0.31°C and 38.44±0.11 %RH; full football gear) often seen during football practices or games. The results of our study continue to provide insight into application, effectiveness and scope of the CoreControl™ hand cooling device. It is already understood that proper hydration leads to improved performance, now we can see that in conjunction with hydration, hand cooling decreases body temperature, decreases HR and decreases thermal sensation during exercise within the parameters of this study design. A peripheral hand cooling modality with negative pressure also leads to an improved performance in power, agility and speed tasks after intense exercise in the heat. Our results suggest that this is an adequate cooling modality when applied as tested and paired with proper hydration protocols in mildly hyperthermic football athletes.

Conclusions

Uncompensable heat stress presents a unique environmental obstacle where a peripheral cooling device could potentially improve the outcome. Within our design, we found that using a peripheral hand cooling modality in uncompensable heat stress lowered physiological variables and

improved performance variables when coupled with fluid replacement. This was shown as a decrease in T_{RE} , HR, thirst and thermal perception and large MD and effect sizes for BESS, REACT, FF and SPT tasks.

References

1. Gonzalez-Alonso J. Hyperthermia impairs brain, heart and muscle function in exercising humans. *Sports Med.* 2007;37(4-5):371-373.
2. Tucker R. The anticipatory regulation of performance: The physiological basis for pacing strategies and the development of a perception-based model for exercise performance. *Br J Sports Med.* 2009;43(6):392-400.
3. Nybo L, Nielsen B. Hyperthermia and central fatigue during prolonged exercise in humans. *J Appl Physiol.* 2001;91(3):1055-1060.
4. Todd G, Butler JE, Taylor JL, Gandevia SC. Hyperthermia: A failure of the motor cortex and the muscle. *J Physiol.* 2005;563(Pt 2):621-631.
5. Casa DJ. Exercise in the heat. I. fundamentals of thermal physiology, performance implications, and dehydration. *J Athl Train.* 1999;34(3):246-252.
6. American College of Sports Medicine, Sawka MN, Burke LM, et al. American college of sports medicine position stand. exercise and fluid replacement. *Med Sci Sports Exerc.* 2007;39(2):377-390.
7. Jones LC, Cleary MA, Lopez RM, Zuri RE, Lopez R. Active dehydration impairs upper and lower body anaerobic muscular power. *J Strength Cond Res.* 2008;22(2):455-463.
8. Yoshida T, Takanishi T, Nakai S, Yorimoto A, Morimoto T. The critical level of water deficit causing a decrease in human exercise performance: A practical field study. *Eur J Appl Physiol.* 2002;87(6):529-534.

9. Casa DJ. Exercise in the heat. II. critical concepts in rehydration, exertional heat illnesses, and maximizing athletic performance. *J Athl Train*. 1999;34(3):253-262.
10. 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.
11. Armstrong LE, Maresh CM. The induction and decay of heat acclimatisation in trained athletes. *Sports Med*. 1991;12(5):302-312.
12. Armstrong L, ed. *Exertional heat illnesses*. Champaign, IL: Human Kinetics; 2003.
13. Armstrong LE, Johnson EC, Casa DJ, et al. The american football uniform: Uncompensable heat stress and hyperthermic exhaustion. *J Athl Train*. 2010;45(2):117-127.
14. Morrison S, Sleivert GG, Cheung SS. Passive hyperthermia reduces voluntary activation and isometric force production. *Eur J Appl Physiol*. 2004;91(5-6):729-736.
15. Casa,D.J.,Armstrong,L.E. Heatstroke: A medical emergency. In: Armstrong L, ed. *Exertional heat illnesses*. Champaign,IL: Human Kinetics; 2003:29.
16. 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.
17. Sawka MN, Francesconi RP, Young AJ, Pandolf KB. Influence of hydration level and body fluids on exercise performance in the heat. *JAMA*. 1984;252(9):1165-1169.
18. Rowell LB. *Human circulation regulation during physical stress*. New York: Oxford University Press; 1986:432.

19. Coyle EF, Gonzalez-Alonso J. Cardiovascular drift during prolonged exercise: New perspectives. *Exerc Sport Sci Rev.* 2001;29(2):88-92.
20. Fritzsche RG, Switzer TW, Hodgkinson BJ, Coyle EF. Stroke volume decline during prolonged exercise is influenced by the increase in heart rate. *J Appl Physiol* (1985). 1999;86(3):799-805.
21. Ekelund LG. Circulatory and respiratory adaptation during prolonged exercise in the supine position. *Acta Physiologica Scandinavica.* 1966;68(3-4):382.
22. Johnson JM, Rowell LB. Forearm skin and muscle vascular responses to prolonged leg exercise in man. *J Appl Physiol.* 1975;39(6):920-924.
23. Rowell LB, Marx HJ, Bruce RA, Conn RD, Kusumi F. Reductions in cardiac output, central blood volume, and stroke volume with thermal stress in normal men during exercise. *J Clin Invest.* 1966;45(11):1801-1816.
24. Shaffrath JD, Adams WC. Effects of airflow and work load on cardiovascular drift and skin blood flow. *J Appl Physiol Respir Environ Exerc Physiol.* 1984;56(5):1411-1417.
25. Ganio MS, Wingo JE, Carroll CE, Thomas MK, Cureton KJ. Fluid ingestion attenuates the decline in VO₂peak associated with cardiovascular drift. *Med Sci Sports Exerc.* 2006;38(5):901-909.
26. Wingo JE, Lafrenz AJ, Ganio MS. Effect of cardiovascular drift on maximal oxygen uptake at two ambient temperatures. *Med Sci Sports Exerc.* 2005;37:S169.
27. Wingo JE, Cureton KJ. Maximal oxygen uptake after attenuation of cardiovascular drift during heat stress. *Aviat Space Environ Med.* 2006;77(7):687-694.

28. Wingo JE, Cureton KJ. Body cooling attenuates the decrease in maximal oxygen uptake associated with cardiovascular drift during heat stress. *Eur J Appl Physiol*. 2006;98(1):97-104.
29. Galloway SD, Maughan RJ. Effects of ambient temperature on the capacity to perform prolonged cycle exercise in man. *Med Sci Sports Exerc*. 1997;29(9):1240-1249.
30. Nielsen B. Olympics in atlanta: A fight against physics. *Med Sci Sports Exerc*. 1996;28(6):665-668.
31. Nielsen B, Savard G, Richter EA, Hargreaves M, Saltin B. Muscle blood flow and muscle metabolism during exercise and heat stress. *J Appl Physiol*. 1990;69(3):1040-1046.
32. Marino FE. Anticipatory regulation and avoidance of catastrophe during exercise-induced hyperthermia. *Comp Biochem Physiol B Biochem Mol Biol*. 2004;139(4):561-569.
33. Tucker R, Rauch L, Harley YX, Noakes TD. Impaired exercise performance in the heat is associated with an anticipatory reduction in skeletal muscle recruitment. *Pflugers Arch*. 2004;448(4):422-430.
34. Tattersson AJ, Hahn AG, Martin DT, Febbraio MA. Effects of heat stress on physiological responses and exercise performance in elite cyclists. *J Sci Med Sport*. 2000;3(2):186-193.
35. Cheung SS. Hyperthermia and voluntary exhaustion: Integrating models and future challenges. *Appl Physiol Nutr Metab*. 2007;32(4):808-817.
36. Hitchcock KM, Millard-Stafford ML, Phillips JM, Snow TK. Metabolic and thermoregulatory responses to a simulated american football practice in the heat. *J Strength Cond Res*. 2007;21(3):710-717.

37. Kulka TJ, Kenney WL. Heat balance limits in football uniforms how different uniform ensembles alter the equation. *Phys Sportsmed*. 2002;30(7):29-39.
38. Roberts WO. Exertional heat stroke during a cool weather marathon: A case study. *Med Sci Sports Exerc*. 2006;38(7):1197-1203.
39. Binkley HM, Beckett J, Casa DJ, Kleiner DM, Plummer PE. National athletic trainers' association position statement: Exertional heat illnesses. *J Athl Train*. 2002;37(3):329-343.
40. Cabanac M, White MD. Core temperature thresholds for hyperpnea during passive hyperthermia in humans. *Eur J Appl Physiol Occup Physiol*. 1995;71(1):71-76.
41. Mathews DK, Fox EL, Tanzi D. Physiological responses during exercise and recovery in a football uniform. *J Appl Physiol*. 1969;26(5):611-615.
42. Snow TK, Millard-Stafford ML, Roskopf LB. Body composition profile of NFL football players. *J Strength Cond Res*. 1998;12(3):146-149.
43. Kay D, Marino FE. Fluid ingestion and exercise hyperthermia: Implications for performance, thermoregulation, metabolism and the development of fatigue. *J Sports Sci*. 2000;18(2):71-82.
44. Montain SJ, Coyle EF. Influence of graded dehydration on hyperthermia and cardiovascular drift during exercise. *J Appl Physiol*. 1992;73(4):1340-1350.
45. Casa DJ, Stearns RL, Lopez RM, et al. Influence of hydration on physiological function and performance during trail running in the heat. *J Athl Train*. 2010;45(2):147-156.
46. Armstrong LE, Costill DL, Fink WJ. Influence of diuretic-induced dehydration on competitive running performance. *Med Sci Sports Exerc*. 1985;17(4):456-461.

47. Cook DB, O'Connor PJ, Eubanks SA, Smith JC, Lee M. Naturally occurring muscle pain during exercise: Assessment and experimental evidence. *Med Sci Sports Exerc.* 1997;29(8):999-1012.
48. Castle PC, Macdonald AL, Philp A, Webbhorn A, Watt PW, Maxwell NS. Precooling leg muscle improves intermittent sprint exercise performance in hot, humid conditions. *J Appl Physiol (1985).* 2006;100(4):1377-1384.
49. Sawka MN, Gonzalez RR, Young AJ, et al. Polycythemia and hydration: Effects on thermoregulation and blood volume during exercise-heat stress. *Am J Physiol.* 1988;255(3 Pt 2):R456-63.
50. Hoffman JR, Maresh CM, Armstrong LE, et al. Effects of hydration state on plasma testosterone, cortisol and catecholamine concentrations before and during mild exercise at elevated temperature. *Eur J Appl Physiol Occup Physiol.* 1994;69(4):294-300.
51. Greenleaf JE, Castle BL. Exercise temperature regulation in man during hypohydration and hyperhydration. *J Appl Physiol.* 1971;30(6):847-853.
52. Pincivero DM, Bompa TO. A physiological review of american football. *Sports Med.* 1997;23(4):247-260.
53. Hoffman JR. The applied physiology of american football. *Int J Sports Physiol Perform.* 2008;3(3):387-392.
54. Robbins DW. The national football league (NFL) combine: Does normalized data better predict performance in the NFL draft? *J Strength Cond Res.* 2010;24(11):2888-2899.

55. Harman EA, Rosenstein MT, Frykman PN, Rosenstein RM. The effects of arms and countermovement on vertical jumping. *Med Sci Sports Exerc.* 1990;22(6):825-833.
56. Galpin AJ, Li Y, Lohnes CA, Schilling BK. A 4-week choice foot speed and choice reaction training program improves agility in previously non-agility trained, but active men and women. *J Strength Cond Res.* 2008;22(6):1901-1907.
57. Sirotic AC, Coutts AJ. The reliability of physiological and performance measures during simulated team-sport running on a non-motorised treadmill. *J Sci Med Sport.* 2008;11(5):500-509.
58. Distefano LJ, Casa DJ, Vansumeren MM, et al. Hypohydration and hyperthermia impair neuromuscular control after exercise. *Med Sci Sports Exerc.* 2012.
59. Ranalli GF, Demartini JK, Casa DJ, McDermott BP, Armstrong LE, Maresh CM. Effect of body cooling on subsequent aerobic and anaerobic exercise performance: A systematic review. *J Strength Cond Res.* 2010;24(12):3488-3496.
60. Casa DJ, McDermott BP, Lee EC, Yeargin SW, Armstrong LE, Maresh CM. Cold water immersion: The gold standard for exertional heatstroke treatment. *Exerc Sport Sci Rev.* 2007;35(3):141-149.
61. Duffield R, Marino FE. Effects of pre-cooling procedures on intermittent-sprint exercise performance in warm conditions. *Eur J Appl Physiol.* 2007;100(6):727-735.
62. Hornery DJ, Papalia S, Mujika I, Hahn A. Physiological and performance benefits of halftime cooling. *J Sci Med Sport.* 2005;8(1):15-25.

63. Quod MJ, Martin DT, Laursen PB, et al. Practical precooling: Effect on cycling time trial performance in warm conditions. *J Sports Sci.* 2008;26(14):1477-1487.
64. Vaile J, O'Hagan C, Stefanovic B, Walker M, Gill N, Askew CD. Effect of cold water immersion on repeated cycling performance and limb blood flow. *Br J Sports Med.* 2011;45(10):825-829.
65. Yeargin SW, Casa DJ, McClung JM, et al. Body cooling between two bouts of exercise in the heat enhances subsequent performance. *J Strength Cond Res.* 2006;20(2):383-389.
66. Cheung S, Robinson A. The influence of upper-body pre-cooling on repeated sprint performance in moderate ambient temperatures. *J Sports Sci.* 2004;22(7):605-612.
67. Duffield R, Dawson B, Bishop D, Fitzsimons 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.
68. Sleivert GG, Cotter JD, Roberts WS, Febbraio MA. 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.
69. Tyler CJ, 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.
70. McDermott BP, Casa DJ, Ganio MS, et al. Acute whole-body cooling for exercise-induced hyperthermia: A systematic review. *J Athl Train.* 2009;44(1):84-93.

71. 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. *J Strength Cond Res*. 2005;19(1):122-128.
72. Lopez RM, Zuri R, Jones L, Cleary MA. 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.
73. Price MJ, Boyd C, Goosey-Tolfrey VL. The physiological effects of pre-event and mid-event cooling during intermittent running in the heat in elite female soccer players. *Appl Physiol Nutr Metab*. 2009;34(5):942-949.
74. Hunter I, Hopkins JT, Casa DJ. Warming up with an ice vest: Core body temperature before and after cross-country racing. *J Athl Train*. 2006;41(4):371-374.
75. Uckert S, Joch W. Effects of warm-up and pre cooling on endurance performance in the heat. *J Sports Med*. 2007;B41:380-384.
76. Arngrimsson SA, Petitt DS, Stueck MG. Cooling vest worn during active warm-up improves 5-km run performance in the heat. *J Appl Physiol*. 2004;96:1867-1874.
77. Rowell LB. Human cardiovascular adjustments to exercise and thermal stress. *Physiol Rev*. 1974;54(1):75-159.
78. Grahn DA, Heller HC. The physiology of mammalian temperature homeostasis. *Int Trauma Anesthesia Critical Care Soc*. 2004:52-61.
79. Bergersen TK. A search for arteriovenous anastomoses in human skin using ultrasound doppler. *Acta Physiol Scand*. 1993;147(2):195-201.

80. Saad AR, Stephens DP, Bennett LA, Charkoudian N, Kosiba WA, Johnson JM. Influence of isometric exercise on blood flow and sweating in glabrous and nonglabrous human skin. *J Appl Physiol*. 2001;91(6):2487-2492.
81. Sangiorgi S, Manelli A, Congiu T, et al. Microvascularization of the human digit as studied by corrosion casting. *J Anat*. 2004;204(2):123-131.
82. Manelli A, Sangiorgi S, Ronga M, Reguzzoni M, Bini A, Raspanti M. Plexiform vascular structures in the human digital dermal layer: A SEM--corrosion casting morphological study. *Eur J Morphol*. 2005;42(4-5):173-177.
83. Grahm D, Brock-Utne JG, Watenpaugh DE, Heller HC. Recovery from mild hypothermia can be accelerated by mechanically distending blood vessels in the hand. *J Appl Physiol*. 1998;85(5):1643-1648.
84. Bligh J. The thermosensitivity of the hypothalamus and thermoregulation in mammals. *Biol Rev Camb Philos Soc*. 1966;41(3):317-368.
85. Gisolfi CV, Lamb DR, Nadel ER. *Perspectives in exercise science and sports medicine: Exercise, heat, and thermoregulation*. Vol 6. Traverse City, MI: Cooper Publishing Group; 1992:389.
86. Grahm DA, Cao VH, Nguyen CM, Liu MT, Heller HC. Work volume and strength training responses to resistive exercise improve with periodic heat extraction from the palm. *J Strength Cond Res*. 2012;26(9):2558-2569.
87. Grahm DA, Cao VH, Heller HC. Heat extraction through the palm of one hand improves aerobic exercise endurance in a hot environment. *J Appl Physiol*. 2005;99(3):972-978.

88. Hsu AR, Hagobian TA, Jacobs KA, Attallah H, Friedlander AL. Effects of heat removal through the hand on metabolism and performance during cycling exercise in the heat. *Can J Appl Physiol.* 2005;30(1):87-104.
89. Walker TB, Zupan MF, McGregor JN, Cantwell AR, Norris TD. Is performance of intermittent intense exercise enhanced by use of a commercial palm cooling device? *J Strength Cond Res.* 2009;23(9):2666-2672.
90. Grahn DA, Dillon JL, Heller HC. Heat loss through the glabrous skin surfaces of heavily insulated, heat-stressed individuals. *J Biomech Eng.* 2009;131(7):071005.
91. Grahn DA, Murray JV, Heller HC. Cooling via one hand improves physical performance in heat-sensitive individuals with multiple sclerosis: A preliminary study. *BMC Neurol.* 2008;8:14-2377-8-14.
92. Kuennen MR, Gillum TL, Amorim FT, Kwon YS, Schneider SM. Palm cooling to reduce heat strain in subjects during simulated armoured vehicle transport. *Eur J Appl Physiol.* 2010;108(6):1217-1223.
93. Kwon YS, Robergs RA, Kravitz LR, Gurney BA, Mermier CM, Schneider SM. Palm cooling delays fatigue during high-intensity bench press exercise. *Med Sci Sports Exerc.* 2010;42(8):1557-1565.
94. 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.
95. Zhang Y, Bishop PA, Casaru C, Davis JK. A new hand-cooling device to enhance firefighter heat strain recovery. *J Occup Environ Hyg.* 2009;6(5):283-288.

96. Goosey-Tolfrey V, Swainson M, Boyd C, Atkinson G, Tolfrey K. The effectiveness of hand cooling at reducing exercise-induced hyperthermia and improving distance-race performance in wheelchair and able-bodied athletes. *J Appl Physiol.* 2008;105(1):37-43.
97. Brodeur VB, Dennett SR, Griffin LS. Exertional hyperthermia, ice baths, and emergency care at the falmouth road race. *J Emerg Nurs.* 1989;15(4):304-312.
98. Costrini A. Emergency treatment of exertional heatstroke and comparison of whole body cooling techniques. *Med Sci Sports Exerc.* 1990;22(1):15-18.
99. House JR, Holmes C, Allsopp AJ. Prevention of heat strain by immersing the hands and forearms in water. *J R Nav Med Serv.* 1997;83(1):26-30.
100. Kielblock AJ, Van Rensburg JP, Franz RM. Body cooling as a method for reducing hyperthermia. an evaluation of techniques. *S Afr Med J.* 1986;69(6):378-380.
101. Tipton MJ, Allsopp A, Balmi PJ, House JR. Hand immersion as a method of cooling and rewarming: A short review. *J R Nav Med Serv.* 1993;79(3):125-131.
102. Al-Aska AK, Yaqub BA, Al-Harthi SS, Al-Dalaan A. Rapid cooling in management of heat stroke: Clinical methods and practical implications. *Annu Saudi Med.* 1987;7:135-138.
103. Minard D. Prevention of heat casualties in marine corps recruits. *Military Med.* 1961;126:261-272.
104. Hostler D, Reis SE, Bednez JC, Kerin S, Suyama J. Comparison of active cooling devices with passive cooling for rehabilitation of firefighters performing exercise in thermal protective clothing: A report from the fireground rehab evaluation (FIRE) trial. *Prehosp Emerg Care.* 2010;14(3):300-309.

105. Selkirk GA, McLellan TM, Wong J. Active versus passive cooling during work in warm environments while wearing firefighting protective clothing. *J Occup Environ Hyg.* 2004;1(8):521-531.
106. Hagobian TA, Jacobs KA, Kiratli BJ, Friedlander AL. Foot cooling reduces exercise-induced hyperthermia in men with spinal cord injury. *Med Sci Sports Exerc.* 2004;36(3):411-417.
107. GREENFIELD AD, KERNOHAN GA, MARSHALL RJ, SHEPHERD JT, WHELAN RF. Heat loss from toes and fore-feet during immersion in cold water. *J Appl Physiol.* 1951;4(1):37-45.
108. GREENFIELD AD, SHEPHERD JT, WHELAN RF. The loss of heat from the hands and from the fingers immersed in cold water. *J Physiol.* 1951;112(3-4):459-475.
109. COLES DR. Heat elimination from the toes during exposure of the foot to subatmospheric pressures. *J Physiol.* 1957;135(1):171-181.
110. COLES DR, GREENFIELD AD. Heat elimination from the hands during local exposure to subatmospheric pressures. *J Physiol.* 1955;128(2):58-9P.
111. Grahn DA, Heller HC. Heat transfer in humans: Lessons from large hibernators. life in the cold: Evolution, mechanisms, adaptation, and application. *Seminar Hypothermia in Trauma Deliberate or Accidental.* 1997.
112. Young AJ, Sawka MN, Epstein Y, Decristofano B, Pandolf KB. Cooling different body surfaces during upper and lower body exercise. *J Appl Physiol (1985).* 1987;63(3):1218-1223.
113. Hunt TN, Ferrara MS, Bornstein RA, Baumgartner TA. The reliability of the modified balance error scoring system. *Clin J Sport Med.* 2009;19(6):471-475.

114. Casa DJ, Roberts WO. Considerations for the medical staff in preventing, identifying and treating exertional heat illnesses. In: Armstrong LE, ed. *Exertional heat illnesses*. Champaign, IL: Human Kinetics; 2003:169.
115. Casa DJ, Anderson JM, Armstrong LE, Maresh CM. Survival strategy: Acute treatment of exertional heat stroke. *J Strength Cond Res*. 2006;20(3):462.
116. Hargreaves M. Physiological limits to exercise performance in the heat. *J Sci Med Sport*. 2008;11(1):66-71.
117. Holt BW, Lambourne K. The impact of different warm-up protocols on vertical jump performance in male collegiate athletes. *J Strength Cond Res*. 2008;22(1):226-229.
118. Bradshaw RJ, Young WB, Russell A, Burge P. Comparison of offensive agility techniques in Australian rules football. *J Sci Med Sport*. 2011;14(1):65-69.
119. Lee DT, Haymes EM. Exercise duration and thermoregulatory responses after whole body precooling. *J Appl Physiol* (1985). 1995;79(6):1971-1976.
120. Booth J, Marino F, Ward JJ. Improved running performance in hot humid conditions following whole body precooling. *Med Sci Sports Exerc*. 1997;29(7):943-949.
121. Kay D, Taaffe DR, Marino FE. Whole-body pre-cooling and heat storage during self-paced cycling performance in warm humid conditions. *J Sports Sci*. 1999;17(12):937-944.
122. Ganio MS, Klau JF, Casa DJ, Armstrong LE, Maresh CM. Effect of caffeine on sport-specific endurance performance: A systematic review. *J Strength Cond Res*. 2009;23(1):315-324.

123. Sierer SP, Battaglini CL, Mihalik JP, Shields EW, Tomasini NT. The national football league combine: Performance differences between drafted and nondrafted players entering the 2004 and 2005 drafts. *J Strength Cond Res.* 2008;22(1):6-12.
124. Candas V, Dufour A. Thermal comfort: Multisensory interactions? *J Physiol Anthropol Appl Human Sci.* 2005;24(1):33-36.

Appendix A

RATING OF PERCEIVED EXERTION SCALE

6

7 Very, Very Light

8

9 Very Light

10

11 Fairly Light

12

13 Somewhat Hard

14

15 Hard

16

17 Very Hard

18

19 Very, Very Hard

20

ENVIRONMENTAL SYMPTOMS QUESTIONNAIRE

Subject #: _____

Date: _____

How Do You Feel Questionnaire

1. Place an X in the box to explain HOW YOU HAVE BEEN FEELING TODAY.

2. PLEASE ANSWER EVERY ITEM.

3. If you did not have the symptom, say NOT AT ALL.

4.

Symptoms	Not At All	A Little	Somewhat	Moderate	A Lot	Extreme
I feel lightheaded						
I have a headache						
I feel dizzy						
I feel thirsty						

I feel weak						
I feel grumpy						
It is hard to breathe						
I will playing at my best						
I have a muscle cramp						
I feel tired						
I feel sick to my stomach (nauseous)						
I feel hot						
I have trouble concentrating						
I have "goose bumps" or chills						

5. SOURCE: Modified from Kobrick and Sampson (1979) and Sampson and Kobrick (1980).

Appendix C

PAIN INTENSITY SCALE

0	NO PAIN AT ALL
½	VERY FAINT PAIN (just noticeable)
1	WEAK PAIN
2	MILD PAIN
3	MODERATE PAIN
4	SOMEWHAT STRONG PAIN
5	STRONG PAIN
6	
7	VERY STRONG PAIN
8	
9	
10	EXTREMELY INTENSE PAIN
	(almost unbearable)
•	UNBEARABLE PAIN

Appendix D

Thermal Scale

0	Unbearably Cold
1	Very Cold
2	Cold
3	Cool
4	Comfortable
5	Warm
6	Hot
7	Very Hot
8	Unbearably Hot

Appendix E

Thirst Scale

1 Not Thirsty At ALL

2

3 A Little Thirsty

4

5 Moderately Thirsty

6

7 Very Thirsty

8

9 Very, Very Thirsty

Fatigue Scale

INDICATE YOUR LEVEL OF OVERALL FATIGUE RIGHT NOW

- 0 No Fatigue At All
- 1 Very Small Amount of Fatigue
- 2 Small Amount of Fatigue
- 3 Moderately Fatigued
- 4 Somewhat Fatigued
- 5 Fatigued
- 6
- 7 Very Fatigued
- 8
- 9 Extremely Fatigued
- 10 Completely Fatigued

Appendix G

HUMAN PERFORMANCE LABORATORY MEDICAL HISTORY QUESTIONNAIRE

Effects of six week exercise prescriptions on running performance and clinical manifestations of cardio-metabolic disease

Study _____ Subject # _____
 Name _____ Sex _____ Age _____ DOB _____
 Street _____
 City _____ State _____ Zip _____ Phone _____
 Email _____

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

YES NO

- Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
- Has your doctor ever denied or restricted your participation in sports or exercise for any reason?
- Do you ever feel discomfort, pressure, or pain in your chest when you do physical activity?
- In the past month, have you had chest pain when you were not doing physical activity?
- Do you lose your balance because of dizziness or do you ever lose consciousness?
- Does your heart race or skip beats during exercise?
- Has a doctor ever ordered a test for you heart? (i.e. EKG, echocardiogram)
- Has anyone in your family died for no apparent reason or died from heart problems or sudden death before the age of 50?
- Have you ever had to spend the night in a hospital?
- Have you ever had surgery?
- Please check the box next to any of the following illnesses with which you have ever been diagnosed or for which you have been treated.

☐ High blood pressure
☐ Asthma
☐ Bladder Problems
☐ Coronary artery disease

☐ Elevated cholesterol
☐ Epilepsy (seizures)
☐ Anemia
☐ Lung problems

☐ Diabetes
☐ Kidney problems
☐ Heart problems
☐ Chronic headaches

YES NO

- Have you had any other significant illnesses not listed above?
- Do you currently have any illness?
- Do you know of any other reason why you should not do physical activity?
- Please list all medications you are currently taking. Make sure to include over-the-counter medications and birth control pills.

Drugs/Supplements/Vitamins

Dose

Frequency (i.e. daily, 2x/day, etc.)

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

17. Please list all allergies you have.

Substance	Reaction
_____	_____
_____	_____
_____	_____

18. Have you smoked? If yes, #/day Age Started If you've quit, what age?

	Have you smoked?	If yes, #/day	Age Started	If you've quit, what age?
<div> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> </div>	Cigarettes	_____	_____	_____
	Cigars	_____	_____	_____
	Pipes	_____	_____	_____

19. Do you have a family history of any of the following problems? If yes, note who in the space provided.

<input type="checkbox"/>	High blood pressure	_____	<input type="checkbox"/>	Heart disease	_____
<input type="checkbox"/>	High cholesterol	_____	<input type="checkbox"/>	Kidney disease	_____
<input type="checkbox"/>	Diabetes	_____	<input type="checkbox"/>	Thyroid disease	_____

20. Please check the box next to any of the following body parts you have injured in the past and provide details.

<input type="checkbox"/>	Head	_____	<input type="checkbox"/>	Hip	_____	<input type="checkbox"/>	Calf/shin	_____
<input type="checkbox"/>	Neck	_____	<input type="checkbox"/>	Thigh	_____	<input type="checkbox"/>	Shoulder	_____
<input type="checkbox"/>	Upper back	_____	<input type="checkbox"/>	Knee	_____	<input type="checkbox"/>	Upper arm	_____
<input type="checkbox"/>	Lower back	_____	<input type="checkbox"/>	Ankle	_____	<input type="checkbox"/>	Elbow	_____
<input type="checkbox"/>	Chest	_____	<input type="checkbox"/>	Foot	_____	<input type="checkbox"/>	Hand/fingers	_____

21. Have you ever had a stress fracture?

☐
☐
☐
☐

22. Have you ever had a disc injury in your back?

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

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:**

