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Examining the Benefits of Prior Heat Exposure on Gastrointestinal Temperature, Heart Rate, and Race Day Finish Time Using a Heat Stress Score Ratio.

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Examining the Benefits of Prior Heat Exposure on Gastrointestinal Temperature, Heart Rate, and Race Day Finish Time Using a Heat Stress Score Ratio.

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Master of Science Thesis

Examining the Benefits of Prior Heat Exposure on Gastrointestinal Temperature, Heart Rate, and Race Day Finish Time Using a Heat Stress Score Ratio.

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Review of the Literature

This review of the literature provides an in depth overview of classical and current studies on the physiological effects of exercise, in addition to the physiological effects of exercise in the heat. In order to understand the adaptations the body undergoes to protect itself from the heat, this review will first discuss the physiological changes the body undergoes while simply exercising in the heat. Second, the adaptations that occur in the body when it's gradually exposed to heat and intensity through exercise and physical activity known commonly as heat acclimatization will be discussed, along with the resulted benefits. Next, this review will explain how one's fitness level has been shown to influence heat tolerance, although not completely replace the benefits of heat acclimatization. Next, modifying factors such as training status, fitness levels, and hydration, which are known to strongly influence heat stress will be explained and last, this review will go over the performance and medical implications of heat acclimatization. This review will discuss how exercise in the heat can overwhelm the body's ability to thermoregulate through a process known as uncompensable heat stress, and how this can increase one's risk for an exertional heat illness (EHI). This review of the literature is aimed for an audience of physically active individuals, more specifically the endurance athlete and more specifically runners. We will conclude this review of the literature discussing the gaps in literature pertaining to the study of heat acclimatization and training for endurance runners.

Physiologic Change During Exercise in the Heat

Exercise and training in the heat is well known to lead to positive physiological adaptations in the body however initial exercise in the heat has demonstrated that athletes often display a reduction in exercise intensity and exercise duration, when compared to exercise in cooler environments. (Armstrong & Maresh, 1991) Weakness, dizziness, and other signs and symptoms are not uncommon amongst athletes who are unfamiliar with exercise in

the heat. (Armstrong, Hubbard, & Kraemer, 1987) For example early investigations by Wyndham, Strydom, and Williams observed the effects of heat and heat acclimatization in miners.(Strydom & Williams, 1969; Wyndham, 1973) In controlled laboratory settings, changes in physiological adaptations were compared in both acclimatized and unacclimatized men during physical activity and they determined that core body temperature and heart rate were decreased, while sweat rate increased in acclimatized individuals.(Wyndham, 1973) This is similar to many other investigations that focused on the topic of heat acclimatization that occurred in the late 1960's.(Wyndham, 1973) These classic investigations demonstrated that through a gradual increase in exercise intensity and duration in the heat, that positive physiological adaptations occur and lead to not only longer duration of exercise, but allow for exercise at a higher intensity due to the heat acclimatization process.

Heat Acclimatization

One's level of heat acclimatization has been identified a pre-disposing factor associated with exertional heat stroke (EHS) fatalities and therefore it is important to determine when these adaptations have occurred.(Rav-Acha, Hadad, Epstein, Heled, & Moran, 2004) Proper identification of when these adaptations occur during the heat acclimatization process has been shown to dramatically decrease the incidence of heat illness and improve physical performance in the heat. Although heat acclimatization is the focus of this review, other predisposing factors associated with EHS such as low physical fitness, high heat load, absence of medical triage, and training during the hottest hours have been identified by Rav-acha et al as shown in Table 1. However, this section will focus on the process and benefits of heat acclimatization. It has been suggested that when the process of heat acclimatization is conducted in a gradual, appropriate, and purposeful manner that the risk of EHI can be significantly reduced. (Armstrong & Maresh, 1991; Armstrong & Stoppani, 2002; Pryor, Casa, & Adams, 2013)

Table 1. Prevalence of pre-disposing factors for exertional heat stroke in six reported fatal cases compared to non- fatal cases from the Israeli Defense Forces.(Rav-Acha et al., 2004)

Predisposing Factor	1	2	3	4	5	6	Total	Nonfatal, % (n)
Physiologic individual limitations								
1 Underlying illness	+	-	+	-	+	-	3/6	17.9 (21/117)
2 Low physical fitness	+	-	+	+	+	+	5/6	71 (66/93)
3 Dehydration	-	+	+	-	-	-	2/6	21.4 (19/89)
4 Sleep deprivation	+	+	-	+	+	+	5/6	40.3 (29/72)
5 Overweight	+	+	-	+	-	-	3/6	64.7 (68/105)
6 Improper acclimatization	+	-	-	+	+	+	4/6	13.7 (13/95)
Total background factors	5	3	3	4	4	3		
Environmental factors								
7 Heat load corresponding to green flag or above (WBGT \geq 27°C)	+	-	+	+	+	+	5/6	16.5 (17/103)
8 High solar radiation	+	+	+	-	+	+	5/6	28 (35/125)
Organizational factors								
9 Physical effort unmatched to physical fitness	+	+	+	+	+	+	6/6	21.6 (23/106)
10 Improper work/rest cycles	+	+	-	-	+	+	4/6	23.8 (20/84)
11 Improper rehydration regimen	+	+	+	-	-	-	3/6	16.4 (14/85)
12 Absence of proper medical triage	+	+	+	+	+	+	6/6	15 (18/120)
13 Training at hottest hours	+	+	+	-	+	+	5/6	35 (42/120)
Disregarding regulations	5	5	4	2	4	4		
Treatment factors								
14 Improper diagnosis	+	+	-	+	-	-	3/6	21.1 (20/95)
15 Improper treatment	+	+	+	+	-	-	4/6	15.1 (15/99)
Total risk factors	14	11	10	9	10	9		

Process

Heat acclimatization is defined as a series of physiological changes that occur in the body after being exposed to the heat stress.(Armstrong & Stoppani, 2002; Casa et al., 2009; Pryor et al., 2013) It can involve restricting the amount of heat exposure until the ability to thermoregulate is normal. These series of adaptations can improve the body's ability to exercise in a relatively hot environment by reducing core body temperature and heart rate, and increasing sweat rate and plasma volume.(Kampmann, Bröde, Schütte, & Griefahn, 2008) The acclimatization process has been documented to occur in approximately 10-14 days with a vast majority of the adaptations occurring during this time (Table 2).(Armstrong & Stoppani, 2002) During the 10-14 days of heat acclimatization, both peripheral and central adaptations occur. Peripheral adaptations that occur with heat acclimatization include increased sensitivity of the sweating response without changing the temperature threshold and the increase of sweat rate.(Pandolf, 1997) Central adaptations seen include a decreased HR, decreased

stroke volume (SV), and a more stable blood pressure level.(Rowell, 1974) Authors have determined that high levels of aerobic fitness were associated with improved peripheral adaptations related to heat dissipation while central adaptations primarily occurred during the heat acclimatization process.(Pandolf, 1997) Combined, the peripheral and central adaptations result in improved heat transfer from the body's core to the skin, and dissipation of the heat to the external environment.

Days of Heat Acclimation (HA) Required for 95% of Each Physiological Adaptation to Occur.	
Adaptation	Days of HA Required
Heart Rate Decrease	3-6
Plasma Volume Increase	3-6
Renal Na ⁺ and Cl Concentration Decrease	3-8
Sweat Na ⁺ and Cl Concentration Decrease	5-10
Core Body Temperature Decrease	5-8
Skin Blood Flow Increase	5-10
Whole- Body Sweat Rate Increase	8-14

Table 2. Adaptations that occur during 14 days of heat acclimation. (Armstrong & Stoppani, 2002)

Armstrong and Maresh(Armstrong & Maresh, 1991) demonstrated that exercise in the heat has a positive effect on various physiological responses, as explained in Table 3. The physiological responses seen in Table 3 are the product of thermoregulatory adaptations in three different exercise and environmental condition scenarios. Strenuous exercise protocols in a hot-dry environment demonstrated major effects in decreased core body temperature, increased heat loss via skin blood flow, increased plasma volume, decreased heart rate, increased VO_{2max} , and adaption to exercise in the heat. Responses demonstrating a moderate effect during the same conditions included decreased skin temperature and improved exercise economy. These adaptations are favorable adaptations that we expect in people who are well

heat acclimatized. When these responses do not occur in an individual, the lack of adaptations can negatively affect the health of an individual while exercise in the heat, thus contradicts the initial goal to obtain health benefits from exercise.

Table 3. The effects of 14 days of passive and strenuous exercise protocols (in cool and hot environments) on selected physiological responses. (Armstrong & Maresh, 1991)

Physiological Responses	Heat Acclimatization without Exercise (Passive)	Cool-Dry Environment (Strenuous exercise protocol)	Hot- Dry Environment (Strenuous exercise protocol)
Lower core temperature at the onset of sweating	++	+	++
Increased heat loss via radiation and convection (skin blood flow)	++	++	++
Increased plasma volume	+	+	++
Decreased heart rate	0	++	++
Decreased core body temperature	++	+	++
Decreased skin temperature	+	+	+
Symbols: 0= Minimal Effect += Moderate Effect ++= Major Effect			

Table 3. Continued. The effects of 14 days of passive and strenuous exercise protocols (in cool and hot environments) on selected physiological responses.(Armstrong & Maresh, 1991)

Physiological Responses	Heat Acclimatization without Exercise (Passive)	Cool-Dry Environment (Strenuous exercise protocol)	Hot- Dry Environment (Strenuous exercise protocol)
Altered metabolic fuel utilization	0	++	++
Increased sympathetic nervous system outflow (efferent)	+	++	++
Increased VO ₂ Max	0	++	++
Improved exercise economy	0	0	+
Adaptation to exercise in cool environment	0	++	++
Adaptation to exercise in hot environment	+	+	++
Symbols: 0= Minimal Effect += Moderate Effect ++= Major Effect			

Benefits

Research has shown that heat acclimatization reduces the risk of EHI by decreasing thermoregulatory and cardiovascular strain.(Trapasso & Cooper, 1989) It is often assumed that the benefits of heat acclimatization are exclusive to exercise that occurs in hot conditions.

However, Adams et al.(Adams, Fox, Fry, & MacDonald, 1975) also reported that partial benefits of heat acclimatization has occurred in runners who train in temperate environmental

conditions (21.9°C, 28-30%RH). An added benefit as a result to HA is increased cardiovascular capacity, which is correlated with the reduction in runners' perception of heat strain. One's perception of effort and feelings do not change as dramatically in response to exercise in the heat, however heat acclimatization has resulted in significant reductions in one's rating of perceived exertion (RPE).(Pryor et al., 2013) A decrease in RPE, which is strongly linked to cardiovascular strain, has been observed with heat acclimatization and is strongly linked with the improved cardiovascular adaptations one experiences.(Muyor, 2013) This reduced perception of effort enables athletes to withstand longer exposure to the heat and perform at a higher intensity.(Pryor et al., 2013) Furthermore, a reduction in undesirable signs and symptoms such as headaches, weakness, dizziness, hyperventilation, and onset of cramps were noted with heat acclimatization.(Armstrong et al., 1987) When coupled with these perceptual improvements, concomitant reductions in heart rate and core body temperature improve running pace and metabolic rate, leading to overall performance benefit.(Byrne, Lee, Chew, Lim, & Tan, 2006)

Heat Balance

In a compensable heat stress environment, the body is able to thermoregulate and maintain heat storage balance through heat gain and heat loss.(Armstrong, 2003) In an exercising individual, metabolic heat is increased, which is then dissipated to the environment in order to maintain proper thermoregulation. However, if this metabolic heat is not dissipated efficiently, internal body temperature levels will rise early during exercise bouts. An increase in metabolic heat storage with a lack of heat dissipation has a physiological strain on the body and leads to uncompensable heat stress.(Armstrong & Maresh, 1991) When the body reaches a point of uncompensable heat stress, this leads to increased risk of experiencing an exertional heat illness (EHI). The relationship showing the negative or positive change in heat storage is expressed in the following equation:(Armstrong, 2003)

$$S = M - (\pm \text{Work}) \pm E \pm R \pm C \pm K$$

Where S= heat storage, M=metabolic heat production, E= evaporation, R=radiation, C=convection, K=conduction. Positive values in this equation show a heat gain while negative values show heat loss. It will limit individuals' ability to exercise at the same intensity and duration compared to the same exercise bout in a cooler environment.(Armstrong & Maresh, 1991)

Heat Tolerance and Training Status

Heat tolerance is strongly influenced by aerobic fitness and body composition. Heat tolerance can be measured via two primary methods. One method to measure heat tolerance includes one's ability to regulate both core body temperature and heart rate during a specific exercise. The other method determines heat tolerance solely by total time of exercise or exercise to a cut-off temperature. Both methods have merit and have been reported in the literature. Interestingly one's level of aerobic fitness has been shown to influence heat tolerance, although not completely replace the benefits of heat acclimatization.(Pandolf, 1997) Endurance training has been shown to improve work-heat tolerance and the rate of heat acclimation.(Pandolf, 1997) When the level of aerobic fitness increases, regardless of age, the threshold level physiological heat strain is improved because of decreased core body temperature and decreased HR. The increase in heart rate, body temperature, and skin blood flow associated with routine exercise has been identified as the primary mechanism behind the improved initial heat acclimatization seen in aerobically fit individuals.(Pandolf, 1997) A decrease in perception of physical work effort through RPE is also noted in the past literature.(Pandolf, 1997) There have been reports on the use of strenuous interval training and continuous training at intensity greater than 50% VO_{2max} to obtain optimal results from endurance training.(Pandolf, 1997) Continuous and interval training with intensities of less than 50% VO_{2max} have been questioned on its effects on work-heat performance.(Pandolf,

1997) Collective findings suggest that aerobic fitness along with morphological variables (percent body fat and weight ratio) may be just as important in thermoregulation and perceptual measures during work or rest in the heat than age and heat acclimatization status alone.(Pandolf, 1997) At the Peachtree Road Race in Atlanta, Georgia, less training and poor performance times compared to the individuals' best performance times were associated with increased risk of heat injury.(England et al., 1982)

Modifiers of Heat Tolerance

Hydration

The average human body is comprised of up to 45-70% water, which may vary depending on the percentage body adiposity.(Kavouras, 2002) The kidneys, which affect water output and factors that stimulate water intake primarily control body water levels. The kidneys can filter up to 150 L of fluid on a daily basis, yet less than 1% is secreted as urine.(Kavouras, 2002) Renal water excretion is mainly regulated by the fluid-regulating hormone called arginine vasopressin (AVP).(Kavouras, 2002) AVP is an anti-diuretic hormone that manifests changes in urine color, urine specific gravity (USG), and urine osmolality when an individual is dehydrated.(Kavouras, 2002) Water balance is important to thermoregulation because dehydration is closely linked to many types of EHI including EHS. Water balance is a behavior that can be addressed to prevent heat illness, or maintain performance or benefit performance.

Euhydration is a term that is used to describe "normal" body water content while a decrease of body water stores is known as dehydration.(Kavouras, 2002) Dehydration can be induced by exposure to heat, fever, insufficient fluid consumption, and physical activity, which in turn increases thermal strain. Increments in environmental heat stress exacerbate the challenge of maintaining fluid balance and increase thermal strain more for the same work effort. Dehydration at rest and during mild and intense physical activity increases core body

temperature to a high degree, which in turn increases, the risk for developing heat illnesses.(Kavouras, 2002) Obtaining a baseline weight is important when using body weight loss as a measure of dehydration. Body weight loss due to fluid loss contributes to an increase in heart rate, where for every 1% of body weight loss an increase of 3 to 5 beats per minute occurs. Also, it has been reported that minimal dehydration can occur between 1-3% body weight loss and significant dehydration between a loss of 4-5%.(Kavouras, 2002) However, once the individual reaches over the threshold of 2% body mass loss, dehydration contributes to a decrease in exercise in performance.(Casa et al., 2000) Furthermore, dehydration can activate an emergency mechanism the body has, better known as thirst. Thirst is activated and controlled by plasma osmolality and plasma volume in order to maintain fluid balance.(Kavouras, 2002) As plasma osmolality increases, plasma volume decreases, thus initiating the perception of thirst.

Plasma osmolality is a stronger regulator of thirst than plasma volume. Research has demonstrated that only 2-3% increase of plasma osmolality induces a strong perception of thirst, compared to a 10% decrease in plasma volume needed for the same thirst response.(Kavouras, 2002) In addition to thirst response, Byrne et al.(Byrne et al., 2006) suggested that the reduced sweat rate and elevated core body temperature observed in the runners were secondary to pre-exercise hypo-hydration, which subsequently induced hyperosmolality, reduced blood volume, and reduced skin blood flow.(Byrne et al., 2006) Because the fluid balance control is complex and dynamic, hydration assessment should be done in a multifaceted manner with the use of multiple urinary indices, such as urine specific gravity (USG), urine color, and urine osmolality.(Armstrong et al., 1994) However determining hydration status is complex and dynamic because it can be misleading at times, especially during rehydration periods. For example, in an instance where a dehydrated individual rapidly consumes large amounts of water their urine color will be light and their USG would be

indicative of a euhydrated state when in fact they remain dehydrated. First morning urine samples, or samples after hours of hydrated state, are encouraged to represent a true euhydrated state versus dehydrated state.(Kavouras, 2002)

Appropriately monitoring hydration status has been a critical measure for athletes, researchers, and the general medical community especially prior to exercise in the heat. The National Athletic Trainers' Association (NATA) recommends the use of the three urinary indices, as well as total body weight loss, to determine the most accurate measure of hydration status.(Cheuvront & Haymes, 2001) Urine color is directly correlated with USG.(Armstrong et al., 1994) An 8-color scale was developed by Armstrong et al.(Armstrong et al., 1994) in order to present an easy to use method to assess hydration status. This color chart correlates with the ranges of USG as seen in Figure 1. Urine color may be affected by medication, vitamins, and foods taken.(Armstrong et al., 1994) This tool is ideal in the field setting to determine an estimate of hydration status because it is quick, easy, and affordable to use. USG measures the relative density of urine in order to determine hydration status. This relative density is the ratio of the density of the urine and is referenced to the density of water. According to Kavouras(Kavouras, 2002), a euhydrated individual has a USG of <1.010 as opposed to a significantly dehydrated individual who has a USG of 1.020-1.030 (Table 4). Measuring USG is also an easy and quick measurement to take in the clinic or laboratory setting. Using a refractometer to measure USG is a more objective measure than using urine color alone, which is why the recommendations suggest coupling the tools in order to determine a more accurate measure of hydration. Urine osmolality measures the concentration of urine. Urine osmolality is a more accurate measure compared to USG, but requires more equipment compared to urine color and USG. The higher the milliosmoles per kilogram (mOsm/kg) the more concentrated the urine is and vice versa. Urine osmolality

greater than 900 mOsm/kg can be used as an indication of dehydration.(Kavouras, 2002)

Aside from measuring urine osmolality, urine color and USG are urinary indices that are commonly used in field studies because they are quick and easy measurements to determine levels of hydration. Knowledge and application of hydration levels can work as a tool to prevent EHI and/or improve performance.

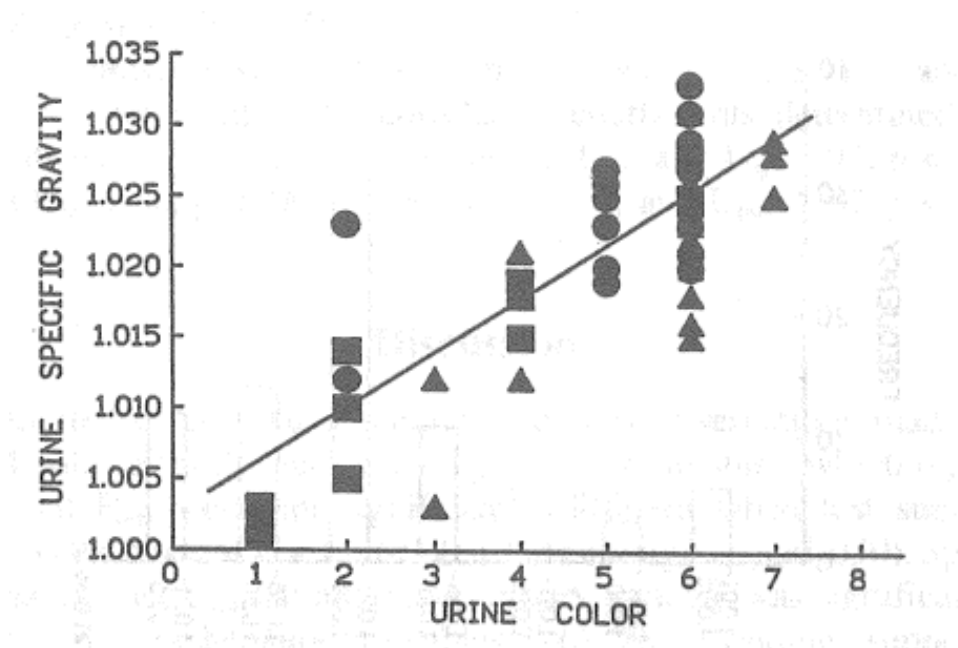


Figure 1. Relationship between pre-exercise measurements of USG and urine color within three separate studies.(Kavouras, 2002)

Table 4. Indices of hydration status using percent body weight change, urine color, and urine specific gravity (USG) to determine level of hydration.(Kavouras, 2002)

Hydration status	% Body weight change*	Urine colour	USG
Well hydrated	+1 to -1	1 or 2	< 1.010
Minimal dehydration	-1 to -3	3 or 4	1.010 – 1.020
Significant dehydration	-4 to -5	5 or 6	1.020 – 1.030
Serious dehydration	< -5	> 6	> 1.030

*% Body weight change = [(baseline body weight – assessment body weight)/baseline weight] × 100. Data from Casa *et al.* [60]. USG, urine specific gravity.

Fitness Level

Running is known to improve and maintain wellness and physical fitness in the general population. With increasing awareness of healthy living and exercise, the popularity of outdoor road race events has significantly risen, more specifically the Falmouth Road Race in Falmouth, MA. (Demartini *et al.*, 2015) Although running provides numerous health benefits, such as lower body temperature during high heat conditions, increased maximum oxygen uptake (VO_{2max}), stroke volume, skin blood flow, and sweat rate, proper and gradually increasing training and intensity is crucial in order to maximize these health benefits. (de Paula Viveiros, Amorim, Alves, Passos, & Meyer, 2012) Apart from the overuse injuries commonly seen in runners, exertional heat stroke (EHS) and exertional heat illnesses (EHI) are great concerns of runners and medical professionals working at road race medical tents. (Roberts, 2010) If not properly trained or heat acclimatized to run in a warm environment, an individual can experience increased heat strain and uncompensable heat stress. (Kampmann *et al.*, 2008)

While endurance training can help improve the rate of heat acclimatization, it requires a period of time for the adaptations to occur. Past research has seen adaptations in endurance training occur in a minimum of 1 week to up to 8-12 weeks. An increase in VO_{2max} from the individuals' baseline by 15% was also seen during these heat acclimatization

adaptations.(Pandolf, 1997) In the Peachtree Road Race, recommendations are given to the runners that they should run at least 37 km per week in the month before the 10km race, and that they should base their predicted finishing time on their best recent 10-km performance time.(England et al., 1982)

Cheuvront and Haymes(Cheuvront & Haymes, 2001) had eight female marathoners train daily in average weather conditions of 30 °C and 64% relative humidity (RH), to heat acclimatize them all. They trained in hot (29.9°C, 55%RH), moderate (20.4°C, 54%RH), and cool (14.3°C, 64%RH) environments. All exercise trials involved a 30km treadmill run at each individuals best marathon race pace (~42km). This ensured that intensity for each individual was the same throughout the trials to ensure greater heat production and physical strain. Results found that changes in exercise heart rate over time trials occurred more quickly in the hot environment trial for female marathoners. Furthermore, they found significantly high body heat storage in the hot running trials than in the moderate and cool trials (Figure 2).(Cheuvront & Haymes, 2001) Cardiovascular functioning improves because heart rate decreases, expansion of plasma volume occurs along with autonomic nervous system habituation that redirects cardiac output to skin capillary beds and active muscles.(Armstrong & Maresh, 1991) This cardiovascular function improvement is concurrent with a decrease in rating of perceived exertion (RPE).

Intensity of exercise plays an important role in the heat acclimatization process. It has been suggested that in order to achieve optimal results in work-heat acclimation during endurance training, the use of continuous or interval training at an intensity of greater than 50% VO_{2Max} is necessary. (Pandolf, 1997) We must understand that higher intensities produce greater heat. That said, heat tolerance would also be a function of the exercise intensity, as well. The higher the fitness level of an individual the higher the intensity that can be tolerated, thus leading to greater body temperature being produced.

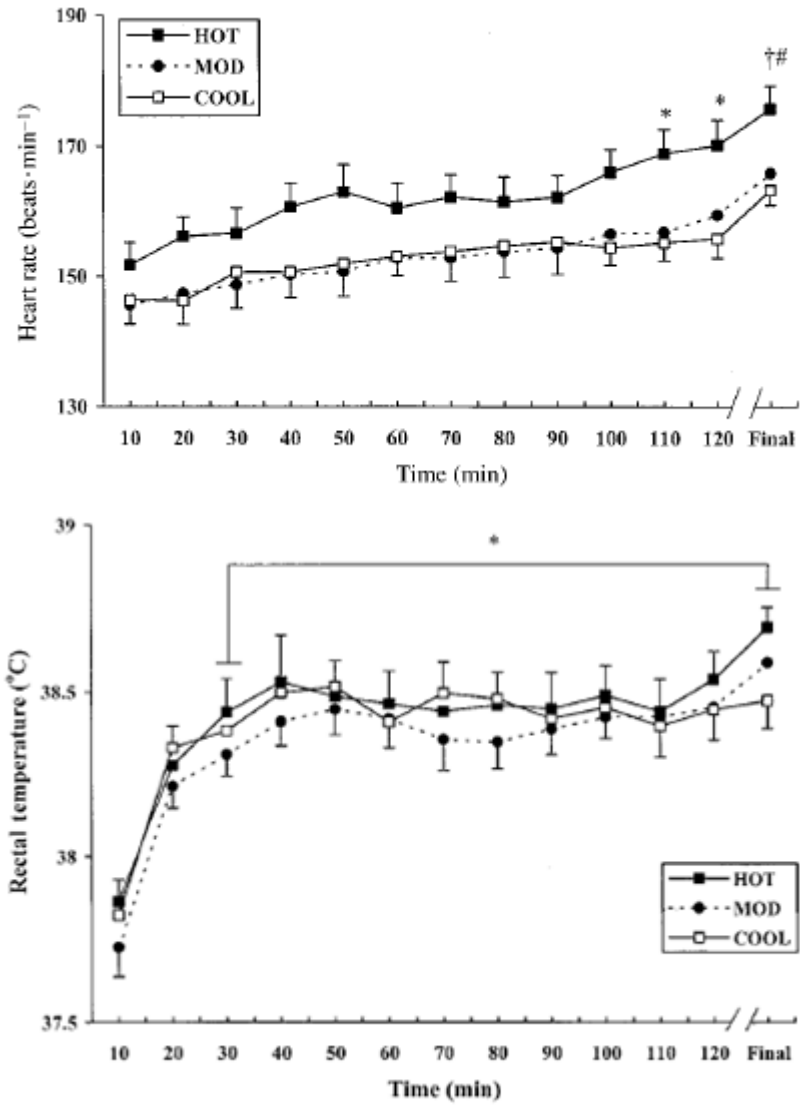


Figure 2. Effects of ad libitum fluid intake on rectal temperature and heart rate responses to exercise in three different environments (hot, moderate, and cool). (Cheuvront & Haymes, 2001)

Performance Implications

Exercise in the heat can take a toll on the body, once factors such as increase in internal body temperature, dehydration, high ambient temperatures, high wet bulb globe temperature (WBGT), and high humidity are taken into account they are linked to a decrease in athletes' performance.(Byrne et al., 2006) The combination of these different factors can also increase the chance of exertional heat illness.(Byrne et al., 2006) Dehydration is associated with increased cardiovascular strain and thermoregulatory strain, and decrease in exercise heat tolerance. Fluid replacement is important to decrease the amount of cardiovascular strain that takes place when an athlete is exercising at a high intensity in a warm environment.(Selkirk & McLellan, 2001) Athletes in a mild dehydrated state, loss of 1±2% of body mass, decrease in exercise performance.(Kavouras, 2002)

High environmental temperature and humidity are also factors that could hinder athletic performance. It is well established in the literature that high WBGT negatively affects running performance.(Ely, Chevront, Roberts, & Montain, 2007) The extent of performance decline varies between studies; however, other endurance competitions are also found to be compromised in high WBGT environment.(Ely et al., 2007) Ely et al.(Ely et al., 2007) analyzed the marathon results and weather data obtained from the Boston, New York, Twin Cities, Grandma`s, Richmond, Hartford, and Vancouver Marathons for 36, 29, 24, 23, 6, 12, and 10 year, respectively.(Ely et al., 2007) Their finding showed a progressive slowing of marathon finish time as the WBGT increases from 5 to 25°C. This seems true for men and women of ranging abilities, however, performance was more negatively affected in slower runners. This may be due to the longer exposure time to the heat and increased time of heat storage.(Ely et al., 2007) Additionally. Montain et al.(Montain, Ely, & Chevront, 2007) produced brief summaries of historical literature regarding the topic of increased WBGT and its effect on

performance. His findings showed that both men and women marathon performance times progressively slow down as weather warms above 5-10°C WBGT.(Montain et al., 2007)

Past literature has found decrements in race times when comparing finishing times with weather conditions of different races during separate years.(Daniels, 2013; Maughan, 2010; Montain et al., 2007; Trapasso & Cooper, 1989) Frederick et al(Maughan, 2010) predicted that for every 5°C that ambient temperature was above or below 12°C, marathon time would slow by approximately 3 minutes or 2% while Brown et al.(Montain et al., 2007) predicted a 7-8% slower time during races in warm conditions.(Maughan, 2010; Montain et al., 2007) Daniels et al(Daniels, 2013) also predicted that at 21°C finishing time would slow by 1.6%, and for every 5°C increase from 21°C it would slow the running performance by 1.6% increments.(Daniels, 2013) Figure 3 shows the predicted decrements in performance based on finishing time and increase in the WBGT.

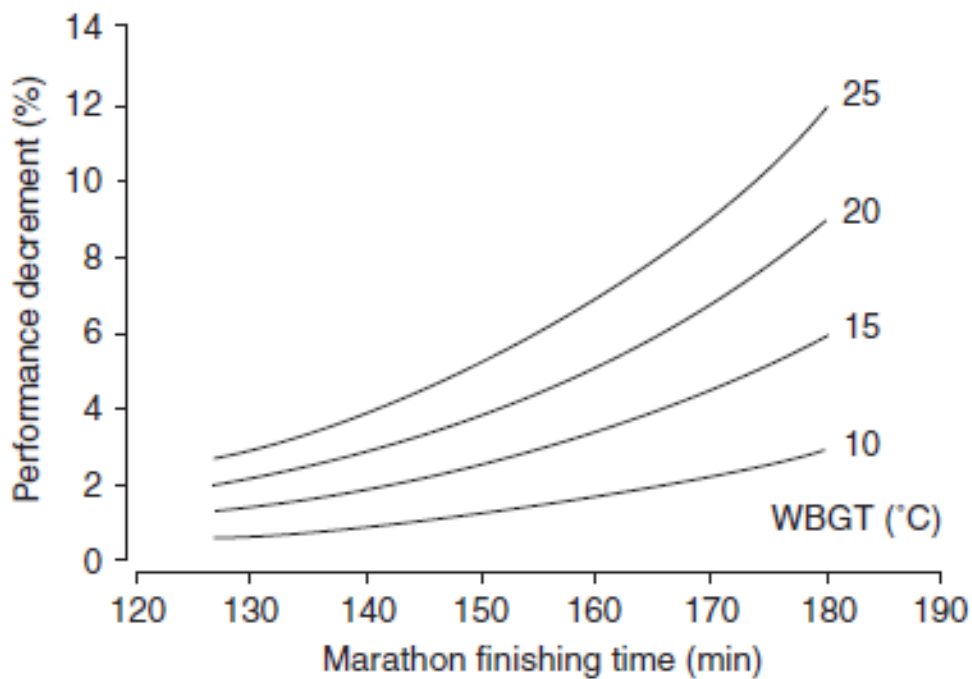


Figure 3. Predicting performance decrements (y-axis) based on projected marathon finishing time (x-axis) with increasing WBGT from the New York City Marathon between 1978 and 2004.(Montain et al., 2007)

The American College of Sports Medicine (ACSM) first stated that WBGT should not exceed 28°C for road running competitions to minimize the risk of thermal injury (Table 5). (Armstrong et al., 1996) In 2007, ACSM reintroduced the recommendations and provided WBGT levels for modification or cancellation of workouts or athletic competition for healthy adults. As WBGT rises workload outside decreases and is ultimately cancelled once WBGT is over 30°C.(American College of Sports Medicine et al., 2007)

Table 5. ACSM Guidelines for WBGT for road running competitions.(American College of Sports Medicine et al., 2007)

WBGT (°C)	Continuous Activity and Competition
• 10	Generally safe; EHS can occur associated with individual factors
10.1-18.3	Generally safe; EHS can occur
18.4-22.2	Risk of EHS and other heat illness begins to rise; high risk individuals should be monitored or not compete
22.3-25.6	Risk for all competitors is increased
25.7-27.8	Risk for unfit, non-acclimatized individuals is high
27.9-30.0	Cancel level for EHS risk
30.1-32.2	Cancel or stop practice and competition
•32.3	Cancel exercise

Medical Implications

Exertional Heat Illness

EHI includes heat syncope, heat cramps, and heat exhaustion. Heat syncope occurs most often in the first 5 days of exercising in the heat due to the lack of adaptations that have occurred in the cardiovascular system causing the individual to faint. (Armstrong & Maresh, 1991; Casa, Almquist, Anderson, & others, 2003) This brief fainting episode is a result of decreased central venous return caused by pooling of blood in the legs and skin. Heat cramps, also known as muscle cramps, usually affect the larger muscle groups. Heat cramps progress into a widespread muscle spasm after muscle excitability occurs. (Casa, Guskiewicz, et al., 2012) Heat cramps are mostly associated with excessive high sodium sweat loss, muscle fatigue, and dehydration. (Casa, Guskiewicz, et al., 2012) The individual doesn't have to be overheated ($>40^{\circ}\text{C}$) for heat cramps to occur. Heat exhaustion is one of the most commonly recognized heat disorders during athletic competitions and events that exhibit the signs and symptoms described earlier. Heat exhaustion typically develops during 1 to 5 days of heat exposure, coupled with electrolyte and water imbalances. The signs and symptoms of heat exhaustion could be a result from peripheral pooling of blood, decreased venous return to the heart, and reduced blood flow to vital organs during exercise. (Armstrong, 2003) However, apparent signs and symptoms are not always present in a case of heat illness, which makes it difficult to recognize quickly. DeMartini (DeMartini et al., 2014) investigated the occurrence of environmental heat illnesses and exertional heat stroke from medical records from selected years at the Falmouth Road Race. They concluded that a clear relationship exists between environmental stress, (measure through ambient temperature and heat index), and the occurrence of EHS or other EHI. (DeMartini et al., 2014) The likelihood of runners experiencing an EHS in harsh, heat environments ($23.3\pm 2.5^{\circ}\text{C}$ ambient temperature, 70 ± 16 RH%, $24\pm 3.5^{\circ}\text{C}$ HI) is significantly increased.

In 1987, Armstrong et al.(Armstrong et al., 1987) first documented the negative responses seen while exercising in the heat. Signs and symptoms observed were abdominal cramps, dizziness, flushed skin, elevated resting heart rate (>160bpm), hyperirritability, vomiting, nausea, and piloerection.(Armstrong et al., 1987) Fourteen unacclimatized males underwent eight days of heat acclimation via treadmill exercise in an environmental chamber ($41\pm 0.5^{\circ}\text{C}$, $39.0\pm 1.7\%$ relative humidity).(Armstrong et al., 1987) The findings in this study showed that 75% of all signs and symptoms and 95.5% of premature termination of trials occurred during later portion of the exercise protocol (periods 5-9) of daily heat acclimation stages. The trials were each a total of 100 minutes divided into 9 exercise periods of 5-10 minutes, followed by a standing rest period of 2-10 minutes. EHS and EHI typically occur during the final portion of road races because of the increased heat storage, dehydration, and decreased metabolic fuel, which correlates with the findings of heat illness signs and symptoms seen during the latter portion of the treadmill exercises. In the 1979, 91% of participants running the Peach Tree Road Race in Georgia experienced one or no symptoms, and 59% who had symptoms reported only weakness, tiredness, or dizziness as their only warning.(England et al., 1982) It may also be difficult for runners to distinguish EHI symptoms, such as weakness, tiredness, or dizziness, apart from general fatigue from the run itself leading them. The lack of noticeable signs and symptoms can then lead to a more dangerous heat illness, known as EHS.

Table 6 shows the number participants and incidence rate of heat injury that occurred in the July 4, 1979 Peachtree Road Race.

Table 6. Incidence of heat injury for July 4, 1979 Peachtree Road Race Participants by sex, age, and residence. *n / 1,000 participants.(England et al., 1982)

Cases of Heat Injury	Participants*	Incidence*
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Total	29	17,632	1.6
<hr/>			
Sex			
Male	27	14,532	1.9
Female	2	2,954	0.7
Unknown	0	147	0
<hr/>			
Age, yrs			
0-9	0	75	0
10-19	2	2,424	0.8
20-29	14	6,657	2.1
30-39	7	6,389	1.1
40-49	5	1,621	3.1
50-59	1	304	3.3
60+	0	40	0
Unknown	0	119	0
<hr/>			
Residence			
Georgia	27	13,258	2.0
Out of State	2	4,336	0.5
Unknown	0	38	0

Exertional Heat Stroke

Exertional heat stroke (EHS) can potentially be a fatal condition if not treated properly. The most accurate method to diagnose a person with EHS is by measuring core body temperature through measuring rectal temperature. (Casa et al., 2003; Casa, Kenny, O'Connor, & Stearns, 2012) The diagnostic temperature of EHS is • 40.5°C or 105°F. (Adams, Stacey, Stacey, & Martin, 2012; Binkley, Beckett, Casa, Kleiner, & Plummer, 2002; Casa, Guskiewicz, et al., 2012; Casa, Kenny, et al., 2012) The second main criterion for diagnosing

EHS is central nervous system (CNS) dysfunction.(Casa, Guskiewicz, et al., 2012; Casa, Kenny, et al., 2012) CNS dysfunction will be demonstrated by the athlete with disorientation, confusion, dizziness, irrational or unusual behavior, inappropriate comments, headache, inability to walk, loss of balance, loss of muscle function, vomiting, diarrhea, or loss of consciousness.(Adams et al., 2012; American College of Sports Medicine et al., 2007; Casa, Armstrong, Ganio, & Yeargin, 2005; Casa, Kenny, et al., 2012; Moreau & Deeter, 2005) Neurologic dysfunction due to elevated body temperature results from both intracranial pressure and decreased arterial blood pressure that leads to a reduction of cerebral perfusion pressure.(Moreau & Deeter, 2005) EHS can become a fatal condition if not recognized and treated properly.

Although recognizing EHS can be as straightforward as measuring core body temperature and assessing CNS dysfunction, there are predisposing factors that you can recognize to help make a diagnosis and prevent the injury from happening. Low physical fitness, sleep deprivation, a high heat load (WBGT •27°C), high solar radiation, and training during the hottest hours of the day were influential in 83% of cases in a study reported by Rav-Acha et al.(Rav-Acha et al., 2004) Non-acclimatized individuals are also at a higher risk of suffering from EHS during intense exercise in warm weather conditions. Rav-Acha et al. showed how six fatal cases of EHS that occurred between 1992- 2002 in the Israeli Defense Force (IDF) were influenced by certain intrinsic and extrinsic factors.(Rav-Acha et al., 2004) These predisposing factors are common in fatal EHS cases. As presented earlier, Table 1 depicts the intrinsic and extrinsic factors that were seen in the 6 fatal cases in the IDF. A report from Marine Corps recruits in training camp suggested that as they became more heat acclimatized the risk of heat injury fell.(Minard, 1961) This report by Minard is agreeable to reports by Rav-Acha (Rav-Acha et al., 2004) associating improper heat acclimatization to 4 of the 6 fatal cases.

Death from EHS is 100% preventable when recognized and treated appropriately during the onset of incident. If not recognized and treated properly, EHS may cause enough tissue damage that can lead to multi-organ failure.(Rav-Acha et al., 2004) Severe lactic acidosis, hyperkalemia, acute renal failure, rhabdomyolysis, and disseminated intravascular coagulation among other medical conditions, are complications that may lead to multi-organ failure and, in some cases, death.(Binkley et al., 2002; Gardner & Kark, 2001)

With the knowledge of the medical implications that can be a result of intolerance to exercise in the heat and the benefits of heat acclimatization, how can we use this knowledge to prevent EHI during competitive endurance events? Is the common athlete adequately preparing and training for a warm weather race to prevent an EHI? These are some of the questions that are raised that have lead to the investigation of training before a warm weather race.

Gaps in Literature

Although the process and benefits of heat acclimatization have been established in previous literature, no study has established the degree of heat exposure required to induce heat acclimatization in preparation for outdoor warm weather races among road race runners.(Armstrong, 2003; Armstrong & Maresh, 1991; Cheuvront & Haymes, 2001; Roberts, 2010) Several indices have been investigated and utilized to measure the amount of physiological strain after an exercise bout. For example, physiological strain index (PSI) was developed to evaluate heat stress in exercising individual. Moran presents a simple Heat Strain Index (HSI) that uses HR and rectal temperature (T_{rec}). The HSI was tested for validation and claims to be an accurate estimate of heat tolerance. However, this HSI does not account for or measure the amount of heat exposure a person experiences that leads them to their physiological strain. Furthermore, no guidelines or recommendations have addressed the

amount of heat exposure required to reduce the risk of EHS and EHI in runners are competing in warm weather races.

References

Adams, Fox, Fry, & MacDonald. (1975). Thermoregulation during marathon running in cool, moderate, and hot environments. *Journal of Applied Physiology*, 38(6), 1030–1037.

- Adams, T., Stacey, E., Stacey, S., & Martin, D. (2012). Exertional heat stroke. *British Journal of Hospital Medicine (London, England: 2005)*, 73(2), 72–78.
- American College of Sports Medicine, Armstrong, L. E., Casa, D. J., Millard-Stafford, M., Moran, D. S., Pyne, S. W., & Roberts, W. O. (2007). American College of Sports Medicine position stand. Exertional heat illness during training and competition. *Medicine and Science in Sports and Exercise*, 39(3), 556–572.
<http://doi.org/10.1249/MSS.0b013e31802fa199>
- Armstrong, L. E. (Ed.). (2003). Exertional Heat Illnesses. In *Exertional Heat Illnesses* (p. 275). Champaign, IL: Human Kinetics.
- Armstrong, L. E., Epstein, Y., Greenleaf, J. E., Haymes, E. M., Hubbard, R. W., Roberts, W. O., & Thompson, P. D. (1996). American College of Sports Medicine position stand. Heat and cold illnesses during distance running. *Medicine and Science in Sports and Exercise*, 28(12), i–x.
- Armstrong, L. E., Hubbard, R. W., & Kraemer, W. J. (1987). Signs and symptoms of heat exhaustion during strenuous exercise., 3(3), 182–189.
- Armstrong, & Maresh. (1991). The induction and decay of heat acclimatisation in trained athletes. *Sports Medicine (Auckland, N.Z.)*, 12(5), 302–312.
- Armstrong, Maresh, Castellani, Bergeron, Kenefick, LaGasse, & Riebe. (1994). Urinary indices of hydration status. *International Journal of Sport Nutrition*, 4(3), 265–279.
- Armstrong, & Stoppani. (2002). Central nervous system control of heat acclimation adaptations: an emerging paradigm. *Reviews in the Neurosciences*, 13(3), 271–285.
- Binkley, H. M., Beckett, J., Casa, D. J., Kleiner, D. M., & Plummer, P. E. (2002). National Athletic Trainers' Association Position Statement: Exertional Heat Illnesses. *Journal of Athletic Training*, 37(3), 329–343.

- Byrne, C., Lee, J. K. W., Chew, S. A. N., Lim, C. L., & Tan, E. Y. M. (2006). Continuous thermoregulatory responses to mass-participation distance running in heat. *Medicine and Science in Sports and Exercise*, *38*(5), 803–810.
<http://doi.org/10.1249/01.mss.0000218134.74238.6a>
- Casa, Almquist, Anderson, S., & others. (2003). Inter-association task force on exertional heat illnesses consensus statement. *NATA News*, *6*, 24–29.
- Casa, Armstrong, Ganio, & Yeargin. (2005). Exertional heat stroke in competitive athletes. *Current Sports Medicine Reports*, *4*(6), 309–317.
- Casa, Armstrong, Hillman, S. K., Montain, S. J., Reiff, R. V., Rich, B. S., ... Stone, J. A. (2000). National athletic trainers' association position statement: fluid replacement for athletes. *Journal of Athletic Training*, *35*(2), 212–224.
- Casa, Csillan, Rice, Baker, Bergeron, M. F., Buchanan, V. M., ... Yeargin, S. W. (2009). Preseason heat-acclimatization guidelines for secondary school athletics. *Journal of Athletic Training*, *44*(3), 332–333. <http://doi.org/10.4085/1062-6050-44.3.332>
- Casa, D. J., Kenny, G. P., O'Connor, F. G., & Stearns, R. L. (2012). Exertional Heat Stroke. In *Preventing Sudden Death in Sport and Physical Activity*. (pp. 53–77). Sudbury, MA: Jones & Bartlett Learning.
- Casa, Guskiewicz, Anderson, S. A., Courson, R. W., Heck, J. F., Jimenez, C. C., ... Walsh, K. M. (2012). National athletic trainers' association position statement: preventing sudden death in sports. *Journal of Athletic Training*, *47*(1), 96–118.
- Chevront, S. N., & Haymes, E. M. (2001). Ad libitum fluid intakes and thermoregulatory responses of female distance runners in three environments. *Journal of Sports Sciences*, *19*(11), 845–854. <http://doi.org/10.1080/026404101753113796>
- Daniels, J. (2013). *Daniels' Running Formula-3rd Edition*. Human Kinetics.

- DeMartini, J. K., Casa, D. J., Belval, L. N., Crago, A., Davis, R. J., Jardine, J. J., & Stearns, R. L. (2014). Environmental conditions and the occurrence of exertional heat illnesses and exertional heat stroke at the Falmouth Road Race. *Journal of Athletic Training, 49*(4), 478–485. <http://doi.org/10.4085/1062-6050-49.3.26>
- Demartini, J. K., Casa, D. J., Stearns, R., Belval, L., Crago, A., Davis, R., & Jardine, J. (2015). Effectiveness of cold water immersion in the treatment of exertional heat stroke at the falmouth road race. *Medicine and Science in Sports and Exercise, 47*(2), 240–245. <http://doi.org/10.1249/MSS.0000000000000409>
- de Paula Viveiros, Amorim, F. T., Alves, M. N. M., Passos, R. L. F., & Meyer, F. (2012). Run performance of middle-aged and young adult runners in the heat. *International Journal of Sports Medicine, 33*(3), 211–217. <http://doi.org/10.1055/s-0031-1295444>
- Ely, M. R., Cheuvront, S. N., Roberts, W. O., & Montain, S. J. (2007). Impact of weather on marathon-running performance. *Medicine and Science in Sports and Exercise, 39*(3), 487–493. <http://doi.org/10.1249/mss.0b013e31802d3aba>
- England, A. C., Fraser, D. W., Hightower, A. W., Tirinnanzi, R., Greenberg, D. J., Powell, K. E., ... Varsha, R. A. (1982). Preventing severe heat injury in runners: suggestions from the 1979 Peachtree Road Race experience. *Annals of Internal Medicine, 97*(2), 196–201.
- Gardner, J. W., & Kark, J. A. (2001). Clinical diagnosis, management, and surveillance of exertional heat illness. *Medical Aspects of Harsh Environments, 1*, 231–279.
- Johnson, E. C., Ganio, M. S., Lee, E. C., Lopez, R. M., McDermott, B. P., Casa, D. J., ... Armstrong, L. E. (2010). Perceptual responses while wearing an American football uniform in the heat. *Journal of Athletic Training, 45*(2), 107–116. <http://doi.org/10.4085/1062-6050-45.2.107>

- Kampmann, B., Bröde, P., Schütte, M., & Griefahn, B. (2008). Lowering of resting core temperature during acclimation is influenced by exercise stimulus. *European Journal of Applied Physiology*, *104*(2), 321–327. <http://doi.org/10.1007/s00421-007-0658-6>
- Kavouras, S. A. (2002). Assessing hydration status. *Current Opinion in Clinical Nutrition and Metabolic Care*, *5*(5), 519–524.
- Mattacola, C., Perrin, D., Gansneder, B., Allen, J., & Mickey, C. (1997). A comparison of visual analog and graphic rating scales for assessing pain following delayed onset muscle soreness., *6*, 38–46.
- Maughan, R. J. (2010). Distance running in hot environments: a thermal challenge to the elite runner. *Scandinavian Journal of Medicine & Science in Sports*, *20*, 95–102. <http://doi.org/10.1111/j.1600-0838.2010.01214.x>
- Minard, D. (1961). Prevention of heat casualties in Marine Corps recruits. Period of 1955-60, with comparative incidence rates and climatic heat stresses in other training categories. *Military Medicine*, *126*, 261–272.
- Montain, S. J., Ely, M. R., & Chevront, S. N. (2007). Marathon performance in thermally stressing conditions. *Sports Medicine (Auckland, N.Z.)*, *37*(4-5), 320–323.
- Moran, D. S., Shitzer, A., & Pandolf, K. B. (1998). A physiological strain index to evaluate heat stress. *American Journal of Physiology - Regulatory, Integrative and Comparative Physiology*, *275*(1), R129–R134.
- Moreau, T. P., & Deeter, M. (2005). Heatstroke--predictable, preventable, treatable. *JAAPA: Official Journal of the American Academy of Physician Assistants*, *18*(8), 30–35.
- Muyor, J. M. (2013). Exercise Intensity and Validity of the Ratings of Perceived Exertion (Borg and OMNI Scales) in an Indoor Cycling Session. *Journal of Human Kinetics*, *39*(1), 93–101.

- Pandolf, K. B. (1997). Aging and human heat tolerance. *Experimental Aging Research*, 23(1), 69–105. <http://doi.org/10.1080/03610739708254027>
- Pryor, R., Casa, D. J., & Adams, A. (2013). Maximizing Athletic Performance in the Heat., 35(6), 24–33.
- Rav-Acha, M., Hadad, E., Epstein, Y., Heled, Y., & Moran, D. S. (2004). Fatal exertional heat stroke: a case series. *The American Journal of the Medical Sciences*, 328(2), 84–87.
- Roberts, W. O. (2010). Determining a “do not start” temperature for a marathon on the basis of adverse outcomes. *Medicine and Science in Sports and Exercise*, 42(2), 226–232. <http://doi.org/10.1249/MSS.0b013e3181b1cdf>
- Rowell, L. B. (1974). Human cardiovascular adjustments to exercise and thermal stress. *Physiological Reviews*, 54(1), 75–159.
- Selkirk, G. A., & McLellan, T. M. (2001). Influence of aerobic fitness and body fatness on tolerance to uncompensable heat stress. *Journal of Applied Physiology (Bethesda, Md.: 1985)*, 91(5), 2055–2063.
- Stearns, Belval, Casa, Klau, Emmanuel, Armstrong, & Maresh. (2013). Two environmental symptoms questionnaires during 10 days of exercise-heat acclimation. *Aviation, Space, and Environmental Medicine*, 84(8), 797–802.
- Strydom, N. B., & Williams, C. G. (1969). Effect of physical conditioning on state of heat acclimatization of Bantu laborers. *Journal of Applied Physiology*, 27(2), 262–265.
- Trapasso, L. M., & Cooper, J. D. (1989). Record performances at the Boston Marathon: biometeorological factors. *International Journal of Biometeorology*, 33(4), 233–237.
- Wyndham, C. H. (1973). The physiology of exercise under heat stress. *Annual Review of Physiology*, 35, 193–220. <http://doi.org/10.1146/annurev.ph.35.030173.001205>

Yamamoto, L. M., Casa, D. J., Stearns, R. L., Yeargin, S. W., McDermott, B. P., Lopez, R. M., ... others. (2008). Validation of a Modified Environmental Symptoms Questionnaire for Exercise in the Heat: 1349: Board# 88 May 28 9: 30 AM-11: 00 AM. *Medicine & Science in Sports & Exercise*, 40(5), S190.

Introduction

The processes and benefits of heat acclimatization discussed in the review of literature help to understand the adaptations the body undergoes to protect itself from the detrimental effects of heat. Heat acclimatization is the process by which physiological adaptations occur in the body when it's gradually exposed to heat and intensity through exercise and physical activity. Failing to heat acclimatize properly can place an individual at greater risk for exertional heat illness and strongly influence performance especially when core body temperature, dehydration, and environmental conditions are less than ideal.

Running is known to improve and maintain wellness and physical fitness in the general population.(Armstrong et al., 1987) With increasing awareness of healthy living and exercise, the popularity of outdoor road race events has significantly raised. Past literature suggests that running provides numerous health benefits, such as higher VO_{2max} , better body temperature control during high heat conditions, higher stroke volume, greater skin blood flow, and higher sweat rates(de Paula Viveiros et al., 2012), and proper training is crucial to maximize these health benefits. Apart from the overuse injuries commonly seen in runners, exertional heat stroke (EHS) and exertional heat illnesses (EHI) are great concerns of runners and medical professionals working at road race medical tents. If the runner is not properly heat acclimatized and trained to run in a warm environment, it could cause a great strain on the body.(Armstrong & Maresh, 1991; Rav-Acha et al., 2004; Strydom & Williams, 1969; Wyndham, 1973)

Falmouth Road Race is one of the many road races that are held in the summer months, which has gained its popularity in the last two decades. The race is held in Falmouth, Massachusetts every year in mid-August, and the level of participant ranges from elite to novice. This race is unique in its distance (11.3km) and the high prevalence of exertional heat illness and heat stroke cases.(Demartini et al., 2015) As this road race gains in popularity, the risk of someone suffering an EHI has increased.(de Paula Viveiros et al., 2012) Research has shown that at the Falmouth Road Race, 274 cases of EHS and 87 cases of heat exhaustion have occurred in the 18 selected years that were investigated in the study, with an overall incidence rate of 2 EHS cases per 1000 finishers.(Demartini et al., 2015) The high incidence rates of EHS during at this race warranted us to further investigate how the runners were preparing themselves before the race.

Heat acclimatization is defined as a series of physiological adaptations that occur in the body to improve the ability to exercise in a hot environment. Research has shown that heat acclimatization reduces the risk of experiencing EHI and EHS by decreasing core body temperature, decreasing heart rate, increasing plasma volume, increasing skin blood flow, and increasing whole body sweat rate.(Armstrong & Stoppani, 2002; Kampmann et al., 2008) It has been used as a preventative measure to reduce the risk of EHS and EHI across all levels for football.(Casa et al., 2009; Casa, Guskiewicz, et al., 2012) This process gradually increases athletes' exposure to the heat while the intensity of physical activity is increased simultaneously to induce physiological adaptations.(Casa et al., 2009) Similarly, runners can reduce their risk of EHS and EHI during an outdoor warm weather race by following proper heat acclimatization recommendations.

The acclimatization process takes 10 to 14 days of continuous heat exposure to observe the adaptations throughout the body.(Armstrong & Stoppani, 2002) Once the

individual is heat acclimatized, the body will better cope with exercise in the heat. Although the benefits of heat acclimatization have been well established, no study to date has investigated the amount of heat exposure that is required to fully acclimatize the runners to the summer races, and there currently is no indices that the runners can utilize to determine their readiness to exercise in the heat. Therefore, this study aimed to examine various aspects of training in endurance runners in the two weeks prior to a warm weather race. Secondly, we aimed to quantify runner's heat exposure during training and compare it to race day heat exposure.

We aim to quantify prior heat exposure and examine resulting race day gastrointestinal temperature (T_{GI}), heart rate (HR), and race finish time (FT). Lastly, delayed onset muscle soreness (DOMS), thermal sensation, thirst sensation(Johnson et al., 2010), environmental symptoms questionnaire (ESQ)(Stearns et al., 2013; Yamamoto et al., 2008), and rating of perceived exertion (RPE)(Muyor, 2013), were also investigated to determine their roles in quantifying the athlete's readiness to exercise in the heat.

Methods

Recruitment for this observational field study began in June of 2014 and completed in August 2014. Once all required documents for participation were collected and approved by principal investigators and medical staff, participants received a link to view a familiarization session via electronic voiceover presentation. After the familiarization, participants received an individual link to the online training log survey (Qualtrics Provo, Utah) and were prompted to complete this survey every day for the 14 days prior to race day. Following the 14 days of successful training log entry from their remote locations all participants met the research team at the Falmouth Road Race Runners Expo. Here participants were familiarized to the Timex Global Positioning System (GPS) watch with heart rate monitor (Run Trainer 1.0, Timex Group USA, Middlebury, CT) and an ingestible thermistor (CorTemp; HQ Inc, Palmetto, FL). On the day of race day, data collection occurred pre-race (PRE) and post-race (POST).

Participant Enrollment

Runners registered for the 2014 Falmouth Road Race were recruited via email and poster flyers. Inclusion criteria were as follows: (1) A current registrant for the 2014 Falmouth Road Race, (2) Between 18 and 60 years old, (3) Predicted finish time of less than 60 minutes, (4) Willing to log an online training log for 14 days leading up to the race day (5) Willing to take

their own rectal temperature (with the provided devices), (6) Willing to complete a menstrual history questionnaire and status form (*female participants only*), (7) Willing to ingest a pill that will measure your core body temperature, (8) No current musculoskeletal injury that limits physical activity, (9) No history of exertional heat stroke within the last three years, (10) No contraindications to ingesting a gastro-intestinal pill, (11) No conditions such as impaired gag reflex, a cardiac pacemaker, or other electro-medical device, (12) No plan to undergo an MRI scan in the near future. If participants met all inclusion and exclusion criteria, interested participants were asked to contact the investigators via email or phone to schedule an informed consent meeting. The informed consent session provided the information regarding the research objectives, procedures, study completion incentives, risk and benefits. In addition, the eligibility criteria were confirmed for subject safety and research consistency. After the completion of informed consent session, student investigators sent an email to each interested participant with a medical history questionnaire, a training history questionnaire, a menstrual history questionnaire (female only), paper consent form, and a link to an online instructional video. After completion of the medical and menstrual history forms, the medical director screened each to confirm no contraindications were present. The participant enrollment was completed when: (1) the participant was medically cleared by our physician to participate in the study, (2) submitted a signed consent form, and (3) submitted a training history questionnaire. The investigators stopped recruitment once the number of interested participants reached thirty-five. Following medical clearance, all participants received an online instructional video, which included instruction on the daily training log data collection. This online instructional video was given to reduce user error and minimize variability of the data collected. In addition, the video included information pertaining to the race day measurements (i.e., flow of testing schedules, questionnaires and tests implemented PRE and POST), and described the questions that were included in the follow-up online log. At the conclusion of the

training video, contact information was provided to the participants for any additional questions and further instructions.

Pre- Race Training Log

Each participant received a subject number and individual link to an online training log that was created for this study (Qualtrics Provo, Utah). Participants logged their daily exercise data leading up to the 2014 Falmouth Road Race. The online training log consisted of the following ten questions:

(1) How many hours of sleep did you get last night?
(2) How many alcoholic drinks did you consume the day before?
(3) Did you experience any of the listed symptoms in the last 24 hours? (Multiple selection question)
(4) Please select the start time of your workout.
(5) What was your heart rate? (Only applicable if the participant owned a heart rate monitor device)
(6) Please rate the level of perceived exertion immediately after the workout.
(7) Where did the workout take place?
(8) Choose your workout venue (Outdoor, outdoor_shade, indoor_AC, indoor_NoAC, pool)
(9) Describe the type of workout you completed. (e.g. run, bike, swim, weight training, cross-fit)
(10) Please log the distance and duration of the workout.

This training log started 14 days prior to race day and in order to be included in the analysis participants were required to log in and complete at least 11 out of 14 days. Participants were instructed to log in and answer the first three questions regardless of the completion of a workout.

Data Collection at Falmouth Road Race

Day Before the Race

All participants were instructed to meet the research team at the race expo the day before the race. Each participant was provided with an ingestible thermistor (CorTemp; HQ Inc, Palmetto, FL) and was instructed to ingest the thermistor the night before, or at minimum six to eight hours before the race to ensure that the thermistor successfully descended into the gastrointestinal tract. The participants were also familiarized with the disposable rectal probe (DataThermII; RG Medical Diagnostics, Southfield MI), Global Positioning System (GPS) watch and heart rate monitor (IRONMAN Run Trainer 1.0; Timex Group USA, Middlebury, CT).

Race Day Pre-race Data Collection

Participants met the research team before the race (PRE) where researchers obtained height, body mass, % body fat, urine color and specific gravity, and perceptual measures. (Table 1). Two portable bathrooms were reserved for research purposes to ensure urine sample collection. Subjects provided a small urine sample for hydration status assessment using a refractometer (A300CL, Atago Inc., Tokyo, Japan) and urine color chart.⁹ Gastrointestinal temperature (T_{gi}) was recorded using a handheld recorder (CorTemp Receiver, HQ. Inc., Palmetto, FL) upon arrival to the research tent. Height, body mass (BWB-800A, Tanita, Tokyo, Japan), and body composition were also recorded. The body composition was measured using 3-site skinfold measurements (Lange Skinfold Calipers, Santa Cruz, CA). Chest, abdomen, and anterior thigh, were used for male participants, and triceps, suprailiac, and anterior thigh were used for female participants. Measurements were taken up to three times per site, and the average was used for calculation. Participants also answered four different perceptual scales: thermal sensation and thirst sensation (Johnson et al., 2010), the modified environmental symptoms questionnaire (ESQ)(Stearns et al., 2013; Yamamoto et al., 2008), and delayed onset of muscle soreness (DOMS)(Mattacola, Perrin, Gansneder, Allen, & Mickey, 1997). The thermal sensation scale is an 8 point validated scale

in 0.5 increments examining perceived thermal (hot/cold) sensations. The thirst sensation scale is a 9 point validated scale in 1.0 increments examining perceived thirst levels, the modified environmental symptoms questionnaire (ESQ) is a 33 question validated scale reflecting environmental symptoms, and delayed onset of muscle soreness (DOMS) was also used to identify current muscle soreness before the race. Lastly, the participants were fitted with the GPS watch and the heart rate (HR) monitor strap, which collected the time, pace, distance and heart rate.

Table 1. Study variables and collection time points. PRE= prior to race, POST= immediately following race, T_{gi} = Gastrointestinal temperature, T_{re} =rectal temperature

Variable	Background Information	PRE	During Race	POST	Follow-Up
Online Training Log	X				X
Resting Heart Rate (bpm)	X				
Body Composition		X			
T_{gi} (°C)		X		X	
T_{re} (°C)				X	
Thermal Sensation		X		X	
Thirst Sensation		X		X	
ESQ		X		X	
DOMS				X	X*
USG		X		X	
Urine Color		X		X	
Height (cm)		X			
Body Mass		X		X	
Heart Rate (bpm)	X	X	X	X	X*
GPS/ Speed (mph)			X		
% Off Predicted Pace				X	

Race Day POST Data Collection

Participants were instructed to check in at the research tent immediately after finishing the race. T_{gi} was measured upon arrival to ensure participant's safety and screen for risk of heat illness. Each participant was then guided to a designated portable bathroom with a

disposable rectal thermometer and a urine sample cup. Participants' body weight was measured before collecting the urine sample. Once the participant successfully inserted the rectal thermometer (10cm past the anal sphincter) and provided a urine sample, they were instructed to sit on a chair under a covered research tent. T_{gi} and rectal temperature (T_{re}) were recorded simultaneously every two minutes from the time the participant sat on the chair. HR and perceptual questionnaire data were also collected during this time. Once the participants finished the race, we obtained their finish time (FT) in order to calculate the percent (%) off of their predicted FT. The following equation was used:

$$\% \text{ Off Predicted Pace} = [(Actual FT - Predicted FT) / Predicted FT] * 100$$

Weather Data

Weather data was obtained using Weather Underground (/, software VWS V15.00). The station utilized was Falmouth Village (weather station ID: KMAFALMO7). Same methodology was used to calculate the weather variables of each participant's daily training location that were obtained from the pre-race training log.

Heat Stress Score

In an effort to quantify the amount of environmental heat exposure experienced by each participant we calculated each individual's Heat Stress Score (HSS) (Equation 1). In order to compare the exposure experienced during the 14 days of training to that of race day, the HSS Ratio (HSS_R) was also calculated. The HSS_R was defined as a ratio between the product of race day temperature ($^{\circ}C$) and the race time (minutes) and the mean product of environmental temperature during the outdoor workouts ($^{\circ}C$) and the exercise duration (minutes) that were reported during the 14 days leading up to the race day.

Equation 1:

Heat Stress Score Ratio (HSS_R): $HSS_R = HSS_E / HSS_T$

where....

Heat Stress Score (**HSS**)= Ambient Temp (C) x Exercise Duration (min)

Average Heat Stress Score Training (**HSS_T**)= $\frac{\text{Ambient temp (}^\circ\text{C) x Exercise duration (min)}}{\text{Number of workouts}}$

Heat Stress Score Event (**HSS_E**)= Race Day temp (°C) x Race Time (min)

$\text{HSS} \leq 1 = \text{HSS}_E \cdot \text{HSS}_T = \text{Race Day Prepared}$

$\text{HSS} > 1 = \text{HSS}_E \cdot \text{HSS}_T = \text{Not Race Day Prepared}$

Performance variables

The chip finish time provided by the Falmouth Road Race was used for race finish times.

Relative performance was also measured and is described in the following formula.

$$\text{Relative Performance (min/km)} = \frac{\text{Actual Pace} - \text{Predicted Pace}}{\text{Predicted Pace}}$$

This was used to predict if a participant successfully predicted their pace and if they were able to maintain their pace throughout the race.

Statistical Analysis

Parametric statistics were used in a Pearson product correlational analysis using SPSS 22.0. Additionally, an ANOVA was used to determine variance between those variables that showed significance in the correlational analysis. Between group comparisons were conducted to determine significance between HSS_R groups. Participants were organized based on their HSS_R : (1) • 1.0 (2) 1.01-2.00 (3) 2.01 or greater. The significance level was set at $p = 0.05$. And lastly, an ANCOVA was used to account for finish time to recognize correlations with the HSS_R .

Results

Participant Demographics

Thirty-two participants, sixteen men (mean \pm SD; age, 40 ± 11 yr; body mass, 76.3 ± 8.5 kg; body fat, $18.6 \pm 5.6\%$) and sixteen women (age, 36.2 ± 10.1 y; body mass, 59.8 ± 7.1 kg; body fat, $19.1 \pm 5.4\%$), who were registered to run in the Falmouth Road Race (Falmouth, Massachusetts) participated in the study. One female participant dropped out due to a family emergency and did not participate in any portion of the study. One male participant dropped out on the race day due to a musculoskeletal injury, but completed the pre-race training log that was administered during the fourteen days leading up to the race. Another female participant dropped out of the study one day before the race day. In summary, a total of 32 participants completed the full protocol of the study.

Race Day Demographics

The average ambient temperature ($25.3 \pm 0.6^\circ\text{C}$), relative humidity ($73.9 \pm 3.98\%$), and heat index (23°C) were calculated for the duration of time that it took for our participants to finish the Falmouth Road Race took place (9:01am-10:36am). The mean morning body mass of male and female participants was $68.04 \pm 11.41\text{kg}$ and average body fat composition was $18.6 \pm 5.6\%$.

Online Training Log

Thirty-two participants completed at least 11 days of the online training log during the 14 days prior to the race. The median response rate for all participants was 13 ± 1 days. The average hours of sleep were 7.3 ± 1.2 hours a day. Seven runners (21%) did not consume alcohol beverage during the fourteen days. Of the 25 runners (78%) who consumed alcohol beverages, the most common amount was 1-2 drinks, followed by 3-5 drinks, and 5+ drinks.

The most popular starting time of the workout was between 5:00am-8:00am. The participants logged total average of 11.44 ± 3.87 workouts during the fourteen days. The total average of outdoor workouts was 7.97 ± 3.86 . 43% (n=14) trained indoor 3.14 ± 1.76 days. 81% of participants completed their training in the New England region (Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut). 13% completed their training in the Mid-Atlantic region, and 3% trained in the South Atlantic region.

Heat Stress Score Ratio (HSS_R)

The average HSS_R was 1.46 ± 0.55 . The average HSS_R in male and female were 1.42 ± 0.64 and 1.50 ± 0.46 , respectively. There was no difference in HSS_R between genders ($r=0.069$, $p=0.709$). Five runners (33%) scored a HSS_R < 1.00 (0.68 ± 0.12). Of those five runners four were male and one was a female. The participants were retrospectively placed into three

groups depending on their HSS_R . Most prepared HSS_R group ($HSS_R < 1.00$), Less prepared HSS_R ($HSS_R 1.00-2.00$, and Least prepared HSS_R ($HSS_R > 2.01$). Groups are depicted in table 6.

Table 6. Heat stress score ratio group demographics.

HSS_R^*	Total runners	Male runners	Female runners
•1.00	5	4	1
1.01-2.00	23	9	14
•2.01	4	1	3

HSS_R^* = Heat Stress Score Ratio
 HSS_R = HSS Event / HSS Training

Temperature Data

The T_{GI} recorded before the race was 37.18 ± 0.44 °C. The T_{GI} temperature recorded immediately post race was 39.6 ± 0.76 °C. The average passive cooling rate after 20 minutes was -0.09 ± 0.03 °C.

HSS_R was not significantly related to immediately post race T_{GI} ($r=0.20$, $p=0.918$). After accounting for finish time, ANCOVA analysis showed that HSS_R was significantly correlated with cooling rate ($p=0.04$, $R^2 = 0.185$, $f=4.718$).

Heart Rate Data

The average HR recorded immediately post race was 171 ± 11 bpm. The average finish time for overall, male and female were $53:34 \pm 0:06$ min and $57:57 \pm 0:05$ min, respectively.

HSS_R was not significantly related to HR immediately post race ($r=0.132$, $p=0.528$).

Finish Time Data

The average finish time was $55:46 \pm 07:28$ min. A positive correlation was found between HSS_R and FT ($p < 0.01$, $r = 0.626$) (Figure 1.) and relative performance ($p=0.003$, $r = -0.505$). Results showed a mean difference of 0:11:30 min between Most prepared and Less prepared groups ($p < 0.001$), a difference of 0:19:23 min between Most prepared and Least

prepared groups ($p < 0.001$), and a difference of 0:07:53 min between Less prepared and Least prepared groups ($p < 0.030$).

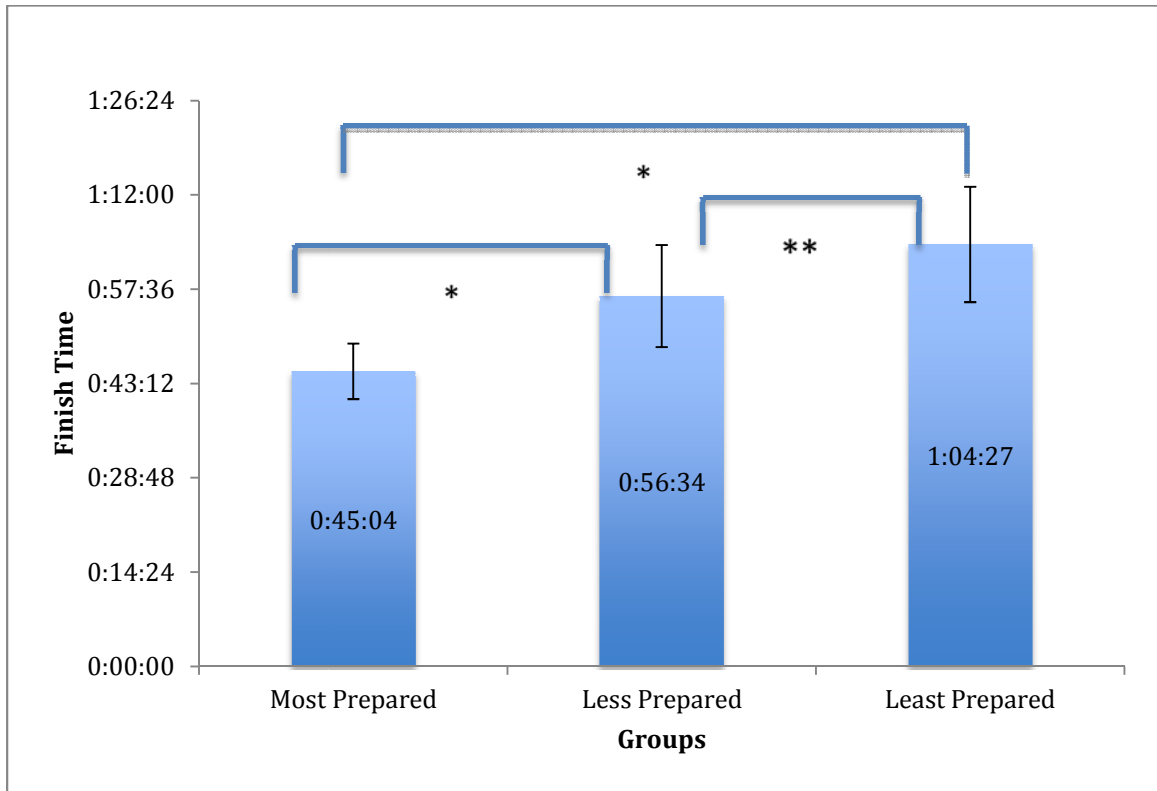


Figure 1. Group comparisons of HSS_r and race finish time. * $p < 0.001$, ** $p = 0.030$.

Groups were different ($p < 0.05$) when comparing HSS_r and percent off predicted FT ($p = 0.016$), however that difference was only between Most Prepared and Least Prepared groups with a mean difference of 19.88% of improved predicted performance ($p = 0.014$). Results depicted in Figure 2. An odds ratio was calculated as a value of 9.3, explaining that those participants who had higher heat exposure were nine times more likely to meet performance goal.

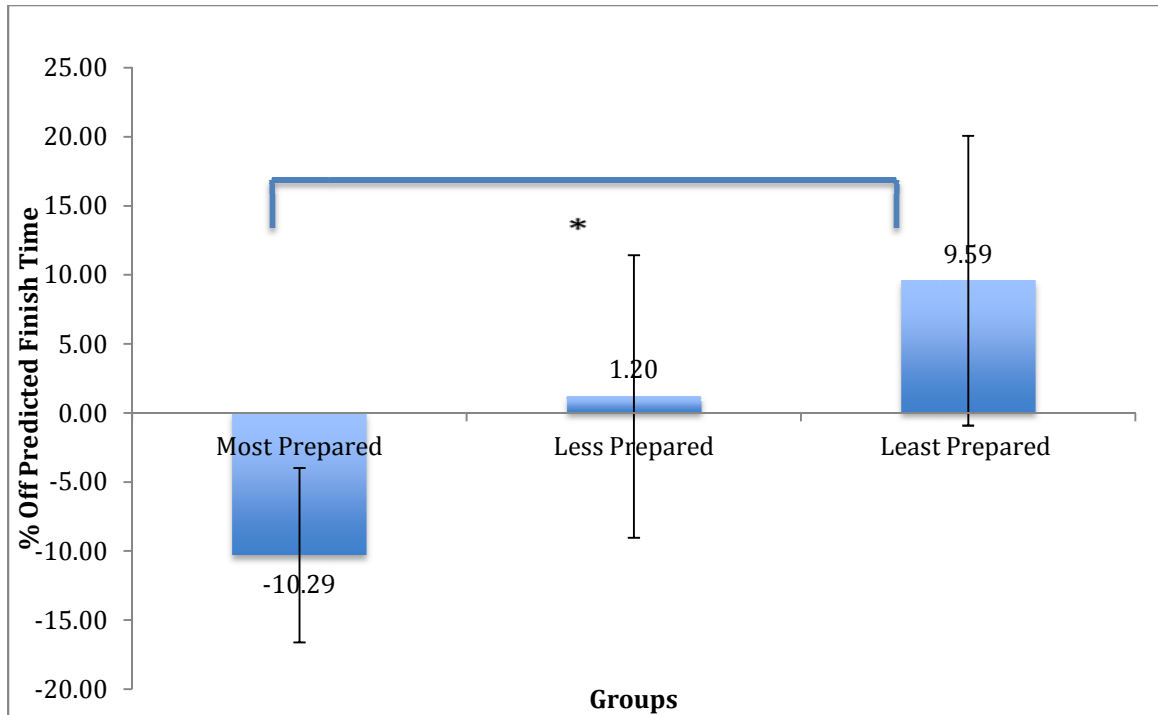


Figure 2. Group comparisons between HSS_R and percent off predicted finish times (FT). * $p=0.014$.

Hydration Data

Average morning urine color was 4 ± 2 and mean USG was 1.014 ± 0.008 . Average post race color was 3 ± 2 and USG 1.009 ± 0.007 . USG was 0.005 ± 0.003 . Average percent body mass loss was $1.2 \pm 0.8\%$.

HSS_R was significantly correlated with body fat composition ($p=0.029$, $r=0.386$) and percent body mass loss (BML%) ($p=0.040$, $r=0.365$).

Perceptual Questionnaire Data

Average pre race thermal, thirst and ESQ were 4 ± 1 , 3 ± 1 , and 4 ± 3 . Average post race thermal, thirst, and ESQ were 5 ± 1 , 5 ± 2 , and 13 ± 8 . HSS_R was not significantly correlated with thermal ($r=0.187$, $p=0.305$), thirst ($r=0.082$, $p=0.662$), or ESQ ($r=0.061$, $p=0.739$) scores.

Pre race DOMS averages for whole body, calves, anterior thighs, posterior thighs, and lower back were 5 ± 6 cm, 7 ± 10 cm, 3 ± 5 cm, 3 ± 4 cm, and 5 ± 7 cm. Immediate Post race DOMS

averages for whole body, calves, anterior thighs, posterior thighs, and lower back were 6±8cm, 7±11cm, 6±9cm, 5±7cm, and 5±9cm. Tables 3,4 and 5 summarize the PRE and POST physiological variables and perceptual questionnaire scores.

Table 3. Physiological variables from pre and post race. No significant correlations between with post race results. GI temperature, p=0.918. HR, p=0.528. USG, p=0.644.

	GI temperature (°C)		Heart rate (bpm)		USG	
	PRE	POST	PRE	POST	PRE	POST
All	37.18±0.44	39.6±0.76	85±16	182±12	1.014±0.008	1.009±0.007
Male	37.1±0.45	39.53±0.72	88±17	183±8	1.014±0.007	1.011±0.007
Female	37.26±0.44	39.67±0.82	81±15	181±15	1.015±0.008	1.008±0.008

Table 4. Perceptual questionnaire scores from pre and post race. *Environmental Symptoms Questionnaire is a total of 33. Thermal Sensation is an 8 point scale in 0.5 increments, and Thirst Scale is a 9 point scale in 1.0 increments

	ESQ*		Thermal sensation		Thirst sensation	
	Pre	Post	Pre	Post	Pre	Post
All	4 ± 3	13 ± 8	4.06±0.5	5.28±1.46	3 ± 1	5 ± 2
Male	3 ± 3	13 ± 7	4.06±0.4	5.47±1.12	2 ± 1	5 ± 2
Female	5 ± 3	14 ± 9	4.06±0.5	5.09±1.75	3 ± 1	6 ± 2

Table 5. Significant findings using VAS (100cm) positively correlated with the amount of high heat exposure with higher DOMS score (Calves, p=0.04, anterior thighs, p=0.05.)

	Whole body	Calves
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	Pre (cm)	Post (cm)	Pre (cm)	Post (cm)	Pre (cm)
All	5 ±6	6±8	7±10	7±11	3±5
Male	7±7	6±8	9±12	8±10	6±6
Female	2±4	6±8	5±8	6±11	1±1

Table 5. cont'd. Delayed onset of muscle spasm scores from pre and post race. Significant findings correlating amount of high heat exposure with higher DOMS score (posterior thighs, $p=0.01$). Post race DOMS calves ($r=0.359$, $p=0.04$), anterior thighs ($r=0.347$, $p=0.05$), and posterior thighs ($r=0.446$, $p=0.01$) were significantly correlated with HSS_R .

	Posterior thighs		Lower back	
	Pre (cm)	Post (cm)	Pre (cm)	Post (cm)
All	3±4	5±7	5±7	5±9
Male	4±5	5±7	4±6	8±10
Female	1±2	5±8	5±8	3±6

Discussion

Exercise leads the body to many physiological adaptations within the human body, regardless of environment. The physiological adaptations that occur when training in a cool environment include: decreased rectal temperature, decreased skin temperature, a lowered threshold temperature for the onset of sweating, decreased heart rate, and increased stroke

volume.(Pandolf, 1997) The physiological adaptations observed in cool environments mirror the physiological adaptations observed during the process of heat acclimatization, except with heat acclimatization a lower metabolic rate is seen(Pandolf, 1997) and the magnitude of the changes are often much greater. The physiological effects of exercise and the process of heat acclimatization are well known, however simple methods to quantify the amount of heat exposure a person experiences during physical training have not been investigated or validated as a guiding factor leading up to a warm weather race.

The physiological strain index (PSI) to evaluate heat stress was investigated by Moran(Moran, Shitzer, & Pandolf, 1998) in 1998. Moran explains the many indices that attempted to measure strain accounting for the environment, equipment, and physiological parameters. Moran presents a simple Heat Strain Index (HSI) that uses HR and rectal temperature (T_{rec}). The HSI is widely accepted due to its combination of environmental variables and body activity; metabolic heat, heat transfer between the body and the environment, and total evaporation required.(Moran et al., 1998) The following equation is a suggested, normalized PSI, where T_{re0} and HR_0 are initial measurements and T_{ret} and HR_t are simultaneous measurements taken at any time:(Moran et al., 1998)

$$PSI= 5(T_{ret} - T_{re0}) \times (39.5 - T_{re0})^{-1} + 5(HR_t - HR_0) \times (180 - HR_0)^{-1}$$

The index is scaled between values of 0-10 (Table 6.) and is within the following limits: 36.5°C

• T_{rec} • 39.5°C and 60 • HR •180 beats/min.

Table 6. Calculated PSI from measured HR and T_{rec} obtained from 100 subjects exposed to 120 minutes of heat stress.(Moran et al., 1998)

Strain	PSI	HR, beats/min	T _{re} , °C	n
No/little	0	71 ± 1.0	37.12 ± 0.03	100
	1	90 ± 1.1	37.15 ± 0.04	47
Low	2	103 ± 1.1	37.35 ± 0.03	81
	3	115 ± 1.3	37.61 ± 0.03	80
Moderate	4	125 ± 1.4	37.77 ± 0.04	61
	5	140 ± 1.9	37.99 ± 0.05	28
High	6	145 ± 5.3	38.27 ± 0.07	13
	7	159 ± 1.3	38.60 ± 0.04	5
Very high	8	175	38.7	1
	9			0
	10			0

Values are means ± SE (*n* is no. of subjects). Heat stress, 40°C, 40% relative humidity, 1.34 m/s at 2% grade; PSI, physiological stress index; HR, heart rate. No data available for very high strain.

The advantages of the HSI are that it is calculated while the individual is exposed to heat stress without having to wait until the end of exposure to analyze the degree of heat stress. This calculation comes from the measurements describing the cardiovascular system and thermoregulatory system, which are two main systems seen in the process of heat acclimatization.

Like the HSI, the same idea was modeled in the HSS_r to use two simple parameters, [(ambient temperature °C and duration of activity (mins)], to describe the amount of heat exposure an individual is experiencing. Although the HSI measures the amount of heat stress strain, the HSS_r is a novel but preliminary attempt to quantify the amount of heat exposure experienced prior to a warm weather road race and the subsequent thermoregulatory responses.

This field study was novel in its successful use of an online survey to track participants' training 14 days prior to an 11.3km warm weather race. To our knowledge, there has not been a field study that has tracked the training of runners in order to quantify the amount of heat exposure prior to their participation in a warm weather road race. Studies have examined heat

acclimation in a controlled environmental chamber, however there is little evidence in the literature demonstrating methods to quantify amount of outdoor heat exposure and the degree of heat acclimatization before an outdoor race. This is the first study to integrate the use of a HSS_r to quantify the amount of heat exposure a participant was exposed to prior to an outdoor race event.

The use of the HSS_r appears to be related to the performance differences observed during the race. Also, the Most Prepared group with a lower HSS_r had a 13.5% improvement in relative performance (Relative Performance (min/km) = $\frac{Actual\ Pace - Predicted\ Pace}{Predicted\ Pace}$) compared to those who had a reduced amount of heat exposure during training. This difference implies that those participants who had a greater heat exposure during training may have been more heat acclimatized and were able to run at or faster than their predicted pace, even when accounting for individual fitness levels. While this is in line with previous literature demonstrating the physiological benefits of heat acclimatization, this is the first time a simple formula has been devised to quantify this preparedness in relationship to an individual's ability to cope with race day thermal stressors. The HSS_r appears to provide an easy way to quantify one's level of heat exposure. Practically, if a runner plans to train for a race that occurs in warm conditions, they could use previous weather data and compare their recent level of training heat exposure. From the calculation of this value, a runner could determine if their current HSS is similar to the conditions expected during this year's race.

Although no significance correlations were found in HSS_r with T_{GI} and HR, it is difficult to make a final conclusion due to the natural limitations associated with this study. First, we lack a true measure of race time potential, and the ability to determine if subjects attained their maximum performance. Therefore it is hard to determine if T_{GI} and HR were truly not associated with HSS_r because subjects may have been unable to accurately judge their

abilities or because they simply did not race as hard as they could have. It is possible that participants may have experienced successful heat acclimatization adaptations, such as lower core temperature and lower heart rate, meaning their adaptations to heat enhanced their performance on race day. However, because these variables were only taken in a controlled environment on the race day, it became difficult to determine the degree of adaptation one may have experienced during the training. Further investigation is necessary in order to investigate the relationships of HSS_R with T_{GI} and HR.

The results of this study indicated that there were significant differences in finish times in participants who were exposed to higher heat exposure. Participants with a higher heat exposure 14 days before the warm weather race maintained a faster pace than they originally predicted. This suggests that those participants with higher heat exposure were well adapted to the warm climate on the race day and thus were able to perform better than their prediction.

This study can be used as a preliminary study to provide evidence to encourage runners to train in similar weather predicted for a specified race, hopefully leading to higher heat exposure to potentially optimize heat acclimatization when preparing for outdoor warm weather races. Educating runners to protect themselves from warm weather races by training in the appropriate environmental conditions can potentially decrease the amount of exertional heat illnesses from occurring at warm weather races and improving race finish times.

Limitations of the present study include collecting environmental conditions from regional weather stations and not a local measure from a subject's workout venue, which could have varied dramatically. Temperature, relative humidity, and heat index were different throughout workouts due to participants training during different time of day and in different regions. Environmental conditions on race day were not controlled as well. The lack of ability to control environmental conditions depicts the realistic changes of environmental conditions throughout training for warm weather races. No body temperature and heart rate readings

were taken 14 days prior to the race, to compare with their body temperature after the race. Some participants have been training well before the 14 days of data collection, so there was a lack of capturing the effect from previous workouts outside of the study. This made it difficult to recognize any adaptations that may have occurred previous to our study. As previously discussed as well, we lack a true measure of race time potential, and the ability to determine if subjects attained their maximum performance.

Future study may investigate the validity and efficacy of HSS_R in an environmental heat chamber in order to control for environmental conditions and validate the use of the HSS_R . Participants can train in the environmental heat chamber that is pre-set at a specific condition to achieve heat acclimatization status. Internal body temperature, heart rate, sweat rate, stroke volume, and VO_{2Max} can be recorded to track heat acclimatization adaptations seen in previous literature. The idea of the HSS_R can be tested in a heat acclimatization study in order to validate the use of HSS_R and potentially create recommendations for runners participating in outdoor warm weather races.

In summary, the purpose of this study was to investigate the benefits of prior heat exposure on race day performance and physiological variables, such as body temperature and heart rate, and race finish time (FT). This study supported previous literature suggesting that environmental heat exposure aids in accelerating the heat acclimatization process and also posed a potential novel index to quantify the level of heat acclimatization via amount of heat exposure. In future examinations of the heat stress score ratio, research should focus on how the HSS and HSS_R can be refined and improved upon so that it may be an accurate tool to better prepare runners before outdoor races. Through better education and preparation, HSS_R , or a future modified version, may be used to improve race performance.

References

- Adams, Fox, Fry, & MacDonald. (1975). Thermoregulation during marathon running in cool, moderate, and hot environments. *Journal of Applied Physiology*, 38(6), 1030–1037.
- Adams, T., Stacey, E., Stacey, S., & Martin, D. (2012). Exertional heat stroke. *British Journal of Hospital Medicine (London, England: 2005)*, 73(2), 72–78.
- American College of Sports Medicine, Armstrong, L. E., Casa, D. J., Millard-Stafford, M., Moran, D. S., Pyne, S. W., & Roberts, W. O. (2007). American College of Sports Medicine position stand. Exertional heat illness during training and competition. *Medicine and Science in Sports and Exercise*, 39(3), 556–572.
<http://doi.org/10.1249/MSS.0b013e31802fa199>
- Armstrong, L. E. (Ed.). (2003). Exertional Heat Illnesses. In *Exertional Heat Illnesses* (p. 275). Champaign, IL: Human Kinetics.
- Armstrong, L. E., Epstein, Y., Greenleaf, J. E., Haymes, E. M., Hubbard, R. W., Roberts, W. O., & Thompson, P. D. (1996). American College of Sports Medicine position stand. Heat and cold illnesses during distance running. *Medicine and Science in Sports and Exercise*, 28(12), i–x.
- Armstrong, L. E., Hubbard, R. W., & Kraemer, W. J. (1987). Signs and symptoms of heat exhaustion during strenuous exercise., 3(3), 182–189.
- Armstrong, & Maresh. (1991). The induction and decay of heat acclimatisation in trained athletes. *Sports Medicine (Auckland, N.Z.)*, 12(5), 302–312.
- Armstrong, Maresh, Castellani, Bergeron, Kenefick, LaGasse, & Riebe. (1994). Urinary indices of hydration status. *International Journal of Sport Nutrition*, 4(3), 265–279.

- Armstrong, & Stoppani. (2002). Central nervous system control of heat acclimation adaptations: an emerging paradigm. *Reviews in the Neurosciences*, 13(3), 271–285.
- Binkley, H. M., Beckett, J., Casa, D. J., Kleiner, D. M., & Plummer, P. E. (2002). National Athletic Trainers' Association Position Statement: Exertional Heat Illnesses. *Journal of Athletic Training*, 37(3), 329–343.
- Byrne, C., Lee, J. K. W., Chew, S. A. N., Lim, C. L., & Tan, E. Y. M. (2006). Continuous thermoregulatory responses to mass-participation distance running in heat. *Medicine and Science in Sports and Exercise*, 38(5), 803–810.
<http://doi.org/10.1249/01.mss.0000218134.74238.6a>
- Casa, Almquist, Anderson, S., & others. (2003). Inter-association task force on exertional heat illnesses consensus statement. *NATA News*, 6, 24–29.
- Casa, Armstrong, Ganio, & Yeargin. (2005). Exertional heat stroke in competitive athletes. *Current Sports Medicine Reports*, 4(6), 309–317.
- Casa, Armstrong, Hillman, S. K., Montain, S. J., Reiff, R. V., Rich, B. S., ... Stone, J. A. (2000). National athletic trainers' association position statement: fluid replacement for athletes. *Journal of Athletic Training*, 35(2), 212–224.
- Casa, Csillan, Rice, Baker, Bergeron, M. F., Buchanan, V. M., ... Yeargin, S. W. (2009). Preseason heat-acclimatization guidelines for secondary school athletics. *Journal of Athletic Training*, 44(3), 332–333. <http://doi.org/10.4085/1062-6050-44.3.332>
- Casa, D. J., Kenny, G. P., O'Connor, F. G., & Stearns, R. L. (2012). Exertional Heat Stroke. In *Preventing Sudden Death in Sport and Physical Activity*. (pp. 53–77). Sudbury, MA: Jones & Bartlett Learning.

- Casa, Guskiewicz, Anderson, S. A., Courson, R. W., Heck, J. F., Jimenez, C. C., ... Walsh, K. M. (2012). National athletic trainers' association position statement: preventing sudden death in sports. *Journal of Athletic Training, 47*(1), 96–118.
- Cheuvront, S. N., & Haymes, E. M. (2001). Ad libitum fluid intakes and thermoregulatory responses of female distance runners in three environments. *Journal of Sports Sciences, 19*(11), 845–854. <http://doi.org/10.1080/026404101753113796>
- Daniels, J. (2013). *Daniels' Running Formula-3rd Edition*. Human Kinetics.
- DeMartini, J. K., Casa, D. J., Belval, L. N., Crago, A., Davis, R. J., Jardine, J. J., & Stearns, R. L. (2014). Environmental conditions and the occurrence of exertional heat illnesses and exertional heat stroke at the Falmouth Road Race. *Journal of Athletic Training, 49*(4), 478–485. <http://doi.org/10.4085/1062-6050-49.3.26>
- Demartini, J. K., Casa, D. J., Stearns, R., Belval, L., Crago, A., Davis, R., & Jardine, J. (2015). Effectiveness of cold water immersion in the treatment of exertional heat stroke at the falmouth road race. *Medicine and Science in Sports and Exercise, 47*(2), 240–245. <http://doi.org/10.1249/MSS.0000000000000409>
- de Paula Viveiros, Amorim, F. T., Alves, M. N. M., Passos, R. L. F., & Meyer, F. (2012). Run performance of middle-aged and young adult runners in the heat. *International Journal of Sports Medicine, 33*(3), 211–217. <http://doi.org/10.1055/s-0031-1295444>
- Ely, M. R., Cheuvront, S. N., Roberts, W. O., & Montain, S. J. (2007). Impact of weather on marathon-running performance. *Medicine and Science in Sports and Exercise, 39*(3), 487–493. <http://doi.org/10.1249/mss.0b013e31802d3aba>

- England, A. C., Fraser, D. W., Hightower, A. W., Tirinnanzi, R., Greenberg, D. J., Powell, K. E., ... Varsha, R. A. (1982). Preventing severe heat injury in runners: suggestions from the 1979 Peachtree Road Race experience. *Annals of Internal Medicine*, *97*(2), 196–201.
- Gardner, J. W., & Kark, J. A. (2001). Clinical diagnosis, management, and surveillance of exertional heat illness. *Medical Aspects of Harsh Environments*, *1*, 231–279.
- Johnson, E. C., Ganio, M. S., Lee, E. C., Lopez, R. M., McDermott, B. P., Casa, D. J., ... Armstrong, L. E. (2010). Perceptual responses while wearing an American football uniform in the heat. *Journal of Athletic Training*, *45*(2), 107–116.
<http://doi.org/10.4085/1062-6050-45.2.107>
- Kampmann, B., Bröde, P., Schütte, M., & Griefahn, B. (2008). Lowering of resting core temperature during acclimation is influenced by exercise stimulus. *European Journal of Applied Physiology*, *104*(2), 321–327. <http://doi.org/10.1007/s00421-007-0658-6>
- Kavouras, S. A. (2002). Assessing hydration status. *Current Opinion in Clinical Nutrition and Metabolic Care*, *5*(5), 519–524.
- Mattacola, C., Perrin, D., Gansneder, B., Allen, J., & Mickey, C. (1997). A comparison of visual analog and graphic rating scales for assessing pain following delayed onset muscle soreness., *6*, 38–46.
- Maughan, R. J. (2010). Distance running in hot environments: a thermal challenge to the elite runner. *Scandinavian Journal of Medicine & Science in Sports*, *20*, 95–102.
<http://doi.org/10.1111/j.1600-0838.2010.01214.x>

- Minard, D. (1961). Prevention of heat casualties in Marine Corps recruits. Period of 1955-60, with comparative incidence rates and climatic heat stresses in other training categories. *Military Medicine*, 126, 261–272.
- Montain, S. J., Ely, M. R., & Chevront, S. N. (2007). Marathon performance in thermally stressing conditions. *Sports Medicine (Auckland, N.Z.)*, 37(4-5), 320–323.
- Moran, D. S., Shitzer, A., & Pandolf, K. B. (1998). A physiological strain index to evaluate heat stress. *American Journal of Physiology - Regulatory, Integrative and Comparative Physiology*, 275(1), R129–R134.
- Moreau, T. P., & Deeter, M. (2005). Heatstroke--predictable, preventable, treatable. *JAAPA: Official Journal of the American Academy of Physician Assistants*, 18(8), 30–35.
- Muyor, J. M. (2013). Exercise Intensity and Validity of the Ratings of Perceived Exertion (Borg and OMNI Scales) in an Indoor Cycling Session. *Journal of Human Kinetics*, 39(1), 93–101.
- Pandolf, K. B. (1997). Aging and human heat tolerance. *Experimental Aging Research*, 23(1), 69–105. <http://doi.org/10.1080/03610739708254027>
- Pryor, R., Casa, D. J., & Adams, A. (2013). Maximizing Athletic Performance in the Heat., 35(6), 24–33.
- Rav-Acha, M., Hadad, E., Epstein, Y., Heled, Y., & Moran, D. S. (2004). Fatal exertional heat stroke: a case series. *The American Journal of the Medical Sciences*, 328(2), 84–87.
- Roberts, W. O. (2010). Determining a “do not start” temperature for a marathon on the basis of adverse outcomes. *Medicine and Science in Sports and Exercise*, 42(2), 226–232. <http://doi.org/10.1249/MSS.0b013e3181b1cdf>

- Rowell, L. B. (1974). Human cardiovascular adjustments to exercise and thermal stress. *Physiological Reviews*, 54(1), 75–159.
- Selkirk, G. A., & McLellan, T. M. (2001). Influence of aerobic fitness and body fatness on tolerance to uncompensable heat stress. *Journal of Applied Physiology (Bethesda, Md.: 1985)*, 91(5), 2055–2063.
- Stearns, Belval, Casa, Klau, Emmanuel, Armstrong, & Maresh. (2013). Two environmental symptoms questionnaires during 10 days of exercise-heat acclimation. *Aviation, Space, and Environmental Medicine*, 84(8), 797–802.
- Strydom, N. B., & Williams, C. G. (1969). Effect of physical conditioning on state of heat acclimatization of Bantu laborers. *Journal of Applied Physiology*, 27(2), 262–265.
- Trapasso, L. M., & Cooper, J. D. (1989). Record performances at the Boston Marathon: biometeorological factors. *International Journal of Biometeorology*, 33(4), 233–237.
- Wyndham, C. H. (1973). The physiology of exercise under heat stress. *Annual Review of Physiology*, 35, 193–220. <http://doi.org/10.1146/annurev.ph.35.030173.001205>
- Yamamoto, L. M., Casa, D. J., Stearns, R. L., Yeargin, S. W., McDermott, B. P., Lopez, R. M., ... others. (2008). Validation of a Modified Environmental Symptoms Questionnaire for Exercise in the Heat: 1349: Board# 88 May 28 9: 30 AM-11: 00 AM. *Medicine & Science in Sports & Exercise*, 40(5), S190.

Appendices

Appendix A

MENSTRUAL HISTORY QUESTIONNAIRE

NAME: _____ AGE: _____ D.O.B. / _____
/19 _____
Print Please

- 1.) Are you currently pregnant? (please circle) **YES** **NO**
- 2.) Are you currently trying to get pregnant? (please circle) **YES** **NO**
- 3.) On what date did your last period start? (mm/dd/yy)
/ /

- 4.) Are you on any hormonal supplements? (please circle) **YES** **NO**
(e.g., birth control pills, hormone replacement therapy)
- 5.) If YES please list by **NAME** and **DOSE** any medication(s).
Please save the label and bring it with you next time.
- 6.) Are your periods regular? If NO please explain.
- 7.) How many days apart? (e.g. 28 days)
- 8.) How many days does your menstrual flow generally last?

- 9.) Do you have any symptoms with your period such as cramping, bloating, headaches, etc.?
Please describe.
- 10.) Do you have any symptoms associated with menopause? If YES please explain.
- 11.) Do you have symptoms in mid cycle as well as, or instead of, with your menstrual flow?
- 12.) Have you missed any periods in the last year? (please circle) **YES NO**
- 13.) How many times within the last year?

Appendix B

MENSTRUAL HISTORY QUESTIONNAIRE

14.) On what date did your last period start? (mm/dd/yy)
/ /

15.) On what date do you expect your next period start? (mm/dd/yy)
/ /

16.) How many days does your menstrual flow generally last?

17.) Are your periods regular? If NO please explain.

MEMO:

Appendix C

Falmouth Road Race – Pre Race Collection

Subject # _____

Immediate Collection:

- GI Temperature:** _____
- Urine color:** _____
- USG:** _____

Anthropometric Measures:

- Body Weight:** _____
- Height:** _____
- Body Composition:**

Male	Chest 1. 2. 3. Average: _____	Abdomen 1. 2. 3. Average: _____	Anterior Thigh 1. 2. 3. Average: _____
Female	Triceps 1. 2. 3.	Supra-Iliac 1. 2. 3.	Anterior Thigh 1. 2. 3.

	Average: _____	Average: _____	Average: _____
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Perceptual Packet:

- Thermal Sensation
- Thirst Sensation
- ESQ
- DOMS

***FEMALES ONLY:**

- Menstrual Status Questionnaire

Timex HR/ Watch Fitting

- Fitted for HR monitor
- Heart Rate: _____ bpm
- Fitted for Timex Watch

Appendix D

Thermal Sensation Scale

0.0	Unbearably Cold
0.5	
1.0	Very Cold
1.5	
2.0	Cold
2.5	
3.0	Cool
3.5	
4.0	Comfortable
4.5	
5.0	Warm
5.5	
6.0	Hot
6.5	
7.0	Very Hot
7.5	
8.0	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

Appendix F

How Do You Feel Questionnaire

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

PLEASE ANSWER EVERY ITEM.

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

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						

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

Appendix G

Muscle Soreness Questionnaire- DOMS

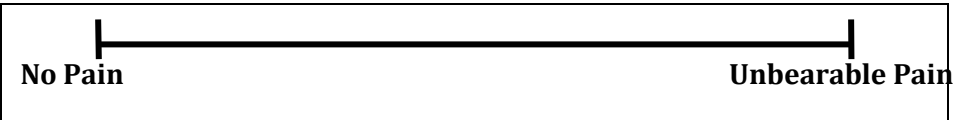
SUBJECT # _____

DATE _____

1. Have you taken any medications to reduce pain today? (*circle*) YES / NO
If yes, please list what and when you have taken and the dose.

2. On the horizontal line below please put a small vertical line across the line that best describes the pain you currently feel. A vertical mark on the extreme LEFT side of the line would indicate that you are experiencing “no pain”; a vertical mark on the extreme RIGHT side of the line would indicate that you are experiencing “unbearable pain”. If your degree of pain is somewhere in between these two extremes, please mark it at the place that most accurately describes your current pain level.

Please mark the line to indicate the pain that you are currently experiencing in the body part.

Whole Body	
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Calves	 No Pain Unbearable Pain
Anterior Thighs	 No Pain Unbearable Pain
Posterior Thighs	 No Pain Unbearable Pain
Lower Back	 No Pain Unbearable Pain