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Use of the Heat Stress Score to Predict Preparedness to Run in an Outdoor, Warm Weather Race

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Use of the Heat Stress Score to Predict Preparedness to Run in an Outdoor, Warm
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I. REVIEW OF THE LITERATURE

FACTORS THAT INFLUENCE PERFORMANCE IN THE HEAT

i. Heat acclimatization and athletic performance

Exercising in the heat induces physiological strain that can lead to impairments in endurance exercise capacity.[1] However, one may reduce physiological strain and optimize performance in the heat with adequate heat acclimatization.[1] Heat acclimatization is the physiologic response produced by repeated exposures to hot environments in which the capacity to withstand heat stress is improved.[2] Adaptation occurs over the course of 10-14 days.[1-4] This gradual adaptation to exercise should include a progressive increase in the intensity and duration of work in the heat, while incorporating a combination of strenuous interval training (< 2 min)[5,6] and continuous exercise (> 20-30 min).[2,3,5-11]

Both laboratory and field studies have reported exercise performance improvement in temperate environments (23°C) following training in the heat (> 30°C).[1,12-17] Athletes might therefore consider having training camps in hot ambient conditions to improve physical performance during in-season[17] and pre-season.[16] Lorenzo et al.[12] examined the impact of heat acclimatization on improving exercise performance in cool and hot environments. Twelve trained cyclists underwent testing which included a maximal aerobic capacity (VO_2max), time trial performance, and lactate threshold (LT) testing in both cool (13°C, 30% relative humidity [RH]), and hot (38°C, 30% RH) environments pre and post a 10-day heat acclimatization (~50% VO_2max in ambient room temperature at 40°C) program.[12] Before VO_2max and LT testing were performed, subjects were either given a warm (41°C) or thermoneutral (34°C) water immersion to

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induce passive hyperthermia, or sustain normothermia respectively.[12] Heat

acclimatization increased VO$_2$max by 5% in cool (pre=66.8 ± 2.1 vs. post=70.2 ± 2.3

ml·kg^{-1}·min^{-1}, P<0.004) and 8% in hot (pre=55.1 ± 2.5 vs. post=59.6 ± 2.0

ml·kg^{-1}·min^{-1}, P<0.007) conditions.[12] Heat acclimatization improved time-trial

performance by 6% in cool (pre=879.8 ± 48.5 vs. post=934.7 ± 50.9 kJ, P<0.005) and 8%

in hot (pre=718.7 ± 42.3 vs. post=776.2 ± 50.9 kJ, P<0.014) conditions, as well as

increased power output at LT by 5% in cool (pre=3.88 ± 0.82 vs. post=4.09 ± 0.76 W/kg,

P<0.002) and hot (pre=3.45 ± 0.80 vs. post=3.60 ± 0.79 W/kg, P<0.001) conditions.[12]

Heat acclimatization increased plasma volume (6.5 ± 0.5%) and maximal cardiac output

in cool and hot conditions respectively (9.1 ± 3.4% and 4.5 ± 4.6%).[12] This study

demonstrated that heat acclimatization improves aerobic performance, LT, and time trial

performance.

King et al.[14] examined muscle metabolism during exercise in the heat in both

acclimatized (ACC) and unacclimatized (UN) individuals. Following an initial heat

exercise test consisting of six hours of intermittent submaximal (50% VO$_2$max) exercise

in the heat (39.7°C, 31.0% RH), unacclimatized participants underwent eight days of heat

acclimatization (39.7°C, 31.0% RH).[14] Subjects then performed the same heat exercise

test, which included two interval sprints, and found that mean muscle glycogen use

during the heat exercise test was lower following acclimatization (ACC=28.6 ± 6.4 and

UN=57.4 ± 5.1 mmol/kg, P<0.05).[14] During the unacclimatized trial only, total work

output during the second sprint was reduced compared to the first sprint (24.01 ± 0.80 vs.

21.56 ± 1.18 kJ, P < 0.05).[14] The study concluded that heat acclimatization produced a

shift in fuel selection during submaximal exercise in the heat, and that muscle glycogen

sparing may be associated with the enhanced ability to perform high intensity exercise following prolonged submaximal exertion in the heat.[14]

Lastly, Racinais et al.[16] examined the physiological and performance responses to a heat acclimatization camp, which involved 18 male Australian Rules Football players who trained for two weeks in hot ambient conditions (31–33°C, 34–50% RH).[16] The players performed a laboratory-based heat-response test (24 min walk + 24 min seated, 44°C), a YoYo Intermittent Recovery Level 2 Test (YoYoIR2; indoor, temperate environment, 23°C) and standardized training drills (STD; outdoor, hot environment, 32°C) at the beginning and end of the camp.[16] The heat-response test identified partial heat acclimatization (e.g., a decrease in skin temperature, heart rate [HR], and sweat sodium concentration, $P<0.05$).[16] In conclusion, the study showed running performance in both hot and temperate environments was improved after an Australians Rules Football training camp in hot ambient conditions that stimulated heat acclimatization.[16]

These studies presented above show the wide variation in heat acclimatization adaptations. Heat acclimatization not only improves aerobic performance, but increases anaerobic performance as well. Individuals who are heat acclimatized additionally have an increased exercise economy both physiologically and perceptually through decreased cardiovascular and thermoregulatory strain.

ii. Hydration

In addition to heat acclimatization, hydration status can affect performance in the heat. Heat exposure during exercise elicits a sweat production response that is influenced by exercise intensity, individual differences (e.g., body mass, body mass index, etc.), environmental conditions, acclimatization status, clothing, and baseline hydration

status.[18] Sweat production is a necessary adaptation to exercise and works in favor to dissipate body heat to attenuate exercise-induced hyperthermia. However, the loss of fluids from the finite reservoir within the body via sweat could impair exercise performance if the exercising individual becomes dehydrated due to sweat loss exceeding fluid intake during activity. If dehydration reaches deficits of 1% to 2% of body mass, cardiovascular and thermoregulatory function, as well as performance are compromised.[18]

Table 1. Indices of Hydration[18]

Condition	% Body Weight Change*	Urine Color	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	-3 to -5	5 or 6	1.021 – 1.030
Serious Dehydration	>5	>6	>1.030

* % Body weight change = [(pre-body weight – post-exercise body weight)/pre-exercise body weight] x 100.
** USG, urine specific gravity.

At rest, 30% to 35% of total body mass is intracellular fluid, 20% to 25% is interstitial fluid, and 5% is plasma.[21] To allow for the movement of water between compartments, the body relies on hydrostatic pressure and osmotic-oncotic gradients.[21] When the body sweats, water moves from the intracellular to extracellular space.[21-23] As a consequence all water compartments are depleted resulting in dehydration.[21] Most of the water deficits associated with dehydration during exercise, however, come from the muscle and skin,[24] resulting in a hypovolemic, hyperosmolality condition thought to precipitate many of the physiologic consequences associated with dehydration decreasing

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performance. This hypovolemic and hyperosmolality may be caused by a decrease in blood perfusion of the muscle tissue during recovery between contractions.[18] Researchers investigating the role of dehydration on muscle strength have generally shown decrements in performance at 5% dehydration or more,[25-29] while some researchers have shown that dehydration of 3% to 4% may also elicit loss of muscle strength.[21,26,30]

Cardiovascular strain is also increased during dehydration (Figure 1). A hypohydrated state will result in a decreased stroke volume, increased HR, increased systemic vascular resistance, and a lower cardiac output and mean arterial pressure.[30] The reduction in stroke volume seen with dehydration appears to be due to reduced central venous pressure, resulting from reduced blood volume and the additional internal temperature increase imposed by dehydration.[31,32] In addition, the magnitude of cardiovascular strain is proportional to the water deficit. Heart rate will rise an additional 3 to 5 beats per minute for every 1% of body weight loss.[33] Maximal aerobic power usually decreases with more than 3% dehydration,[21] but even at 1% to 2% dehydration in a cool environment could reduce aerobic performance.[34,35] Walsh et al.[36] noted a decrease in physical work capacity during cycling as early as less than 2% dehydration during intense exercise in the heat (32°C, 60% RH). When the percentage of dehydration was further increased, physical work capacity during cycling decreased by 35% to 48% and subjects were unable to sustain high intensity exercise.[36]

Cheung et al.[37] researched the effects of heat acclimatization, aerobic fitness, and hydration effects on heat tolerance during uncompensable heat stress and concluded that 2.5% dehydration results in significant performance decrements while exercising in the heat (40°C, 30% RH), regardless of fitness or heat acclimation status. Dehydration also

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decreases the motivation to exercise due to increased perceived exertion, and decreases

the time to exhaustion, even in instances when strength is not compromised.[33]
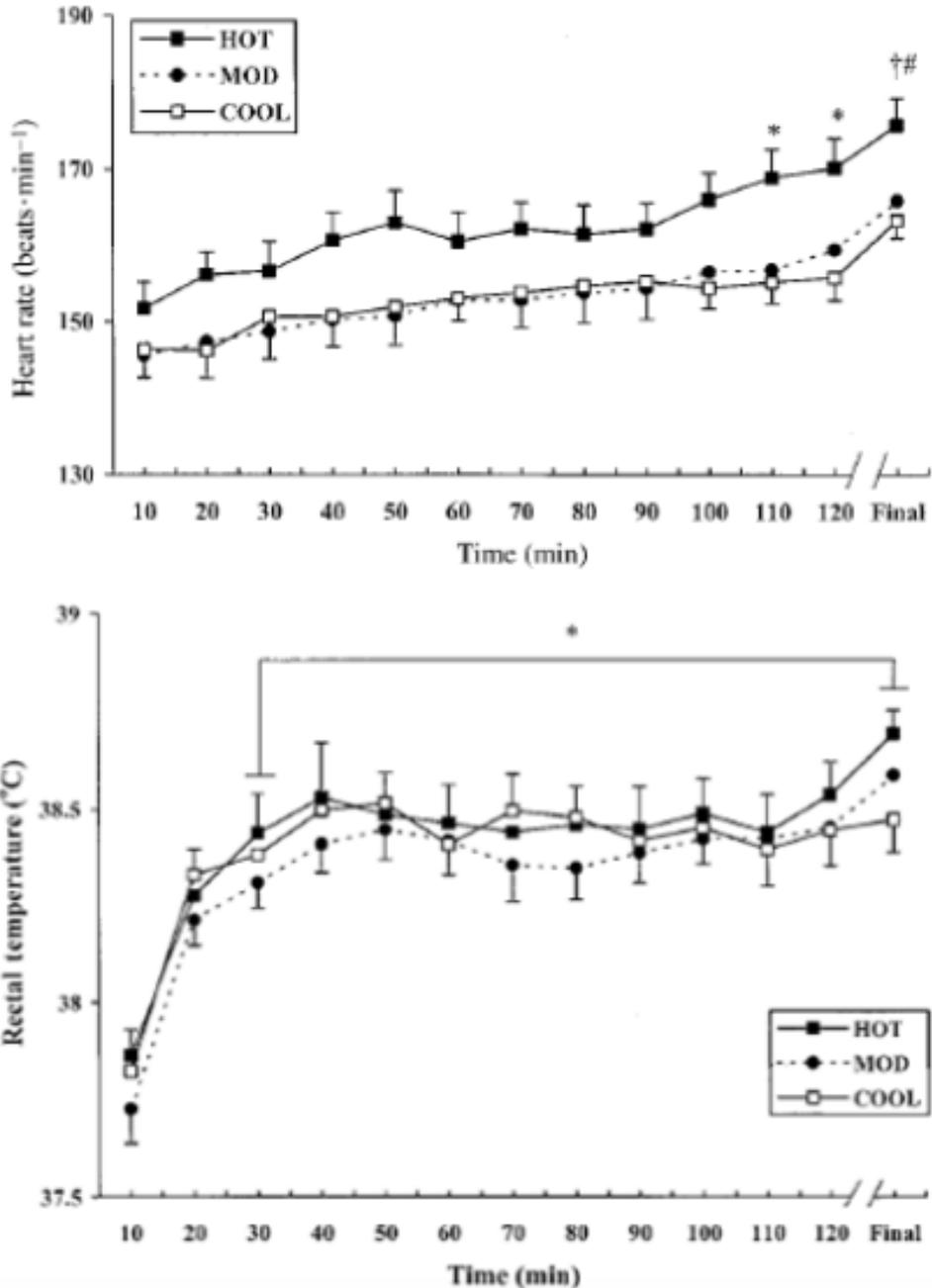
Figure 1. Effects of ad libitum fluid intake on rectal temperature and heart rate responses to exercise in three different environments (hot, moderate, and cool).[38] Researchers concluded that participants in the hot condition were unable to adequately replenish fluids lost during exercise.

iii. Internal Body Temperature

The primary mechanism of heat dissipation during exercise, which regulates body temperature, is the heat lost from the skin's surface via sweat evaporation. Body temperature is also increased in a hypohydrated state due to elevated muscle tissue temperature,[18,39] resulting in decreases in exercise performance, especially in the heat.[40] There are two hypotheses on internal body temperature regulation that explain the decline in exercise performance in the heat: (1) the anticipatory hypothesis, and (2) the critical temperature hypothesis.[40] First, the anticipatory model states that the brain will prematurely stop activity or reduce exercise intensity with an anticipation of body temperature increase, thus protecting the body from reaching unsafe temperature by altering intensity during exercise.[40,41] Second, the critical temperature hypothesis states that the brain has a pre-set critical threshold of 40°C, where the brain will act to decrease the exercise intensity once the body reaches that point.[40] Though different hypotheses, both result a reduction of exercise intensity due to increased thermoregulatory strain.

It has also been shown that a lower body temperature (< 39-40°C) during practice and competition allows athletes to perform longer and at a higher intensity, especially during exercise in the heat.[40,42] Hessemer et al.[42] found that when individuals who are cycling at maximum intensity are cooled prior to the start of the exercise bout, their mean one hour work rate (172 W) was 6.8% larger that those who are not cooled (161 W). Additionally, participant's oxygen uptake (VO_2max) was 9.6% higher (2.86 vs. 2.61 ml·kg·min), and the sweat rate was 20.3% lower when cooled. [42]

It is imperative to minimize sustained elevation of body temperature to reduce the systemic inflammatory response observed during exercise, which is often exacerbated by an increased body temperature. This decrease in stress helps the body recover quicker and

allows the body to perform better in subsequent training sessions or competitions.[40,43] Additionally, research has shown that post exercise cooling reduces inflammation (e.g., IL-1, IL-6, etc.), HR, and cardiac output, and provides perceptual analgesic effects, which when all combined, can help to reduce recovery time.[40,44] Moreover, a systematic review of nine studies concluded that cooling during exercise, while not as extensively investigated, resulted in participants exhibiting improved exercise performance (9.9 ±1.9 %, ES=0.40) in the heat.[45] Wearing an ice vest during exercise was the most effective in improving exercise performance (+21.5%, ES=4.64), compared with cold water ingestion (+11%, ES=1.75) and cooling packs (+8.4%, ES=0.39).[45]

iv. Fitness and cardiovascular strain

Another factor that has been shown to increase running performance in the heat is maintenance of physical fitness. Habitual running provides numerous health benefits, such as lower body temperature during high heat conditions, and increased maximum oxygen uptake, stroke volume, skin blood flow, and sweat rate.[46,47] During exercise in the heat, the body is faced with a challenge of simultaneously providing sufficient blood flow to exercising skeletal muscle while directing sufficient blood to the skin to dissipate heat via convection.[48] Investigations[48,49] have concluded that in healthy subjects, cardiovascular strain during exercise in the heat results mostly from reduced cardiac filling and stroke volume. This occurs due to the redistribution of the blood to the periphery, which may further increase internal body temperature due to the lack of direct heat dissipation mechanism from the core.[48,49] Maximal oxygen uptake is reduced in hot compared to temperate environments,[50-53] with Sawka et al.[54] concluding that maximal oxygen uptake was 0.25 liters per minute lower in a 39°C environment compared to a

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20°C environment. There are no studies to thoroughly explain this phenomena, however one can theorized that thermal stress might result in a displacement of blood to the cutaneous vasculature, which could: (1) reduce the portion of cardiac output perfusing the contracting musculature, or (2) result in a decreased effective central blood volume, thus reducing venous return and cardiac output.[48]

Compensatory responses to these changes include reductions in splanchnic and renal blood flow, increased cardiac contractility, which helps to defend stroke volume in the face of impaired cardiac filling, and increased HR to compensate for decreased stroke volume.[48] If these compensatory responses are insufficient, skin and muscle blood flow will be impaired, causing an increased heat strain and possible uncompensable heat stress leading to a decrease in performance.[46,55] The magnitude of physiological strain imposed by environmental stress depends on the individual's metabolic rate and capacity for heat exchange with the environment.[48] Muscular exercise increases metabolism by 5-15 times the resting rate to provide energy for skeletal muscle contraction, and depending on the type of exercise, 70%-100% of metabolism is released as heat and needs to be dissipated in order to maintain body heat balance.[48] Taken together, aerobically fit individuals who are heat acclimatized and fully hydrated have less body heat storage and perform optimally during exercise under heat stress.

UNCOMPENSABLE HEAT STRESS AND HEAT ACCLIMATIZATION

i. Uncompensable heat stress

When metabolic heat produced by the muscles during activity outpaces body heat transfer to the atmosphere, the body's internal temperature rises uncontrollably to levels that disturb normal organ function. Such stress is described as uncompensable heat stress.

Uncompensable heat stress is characterized by decreases in cardiac output, oxygen delivery to tissues, and vascular transport of heat from deep tissues to the skin, leading to an accelerated elevation of core temperature, tissue hypoxia, metabolic acidosis, and eventually organ dysfunction.[57]

Cerebral and hypothalamic failure seen with heating of the brain also accelerates cell death by disrupting the regulation of blood pressure and blood flow, and limits heat exchange in the intestines promoting bowel tissue hyperthermia and ischemia.[57] The breakdown of the gut cell membrane then allows lipopolysaccharide fragments from intestinal gram-negative bacteria to leak into systemic circulation, inherently increasing the risk of endotoxic shock.[57] At the muscle level, breakdown of fibers (i.e., rhabdomyolysis) occurs when the cells meet the critical threshold (i.e., about 40°C), and muscle membrane permeability increases releasing myoglobin and intracellular potassium which may cause renal tubular toxicity and obstruction and potentially induce cardiac arrhythmias due to increased serum levels respectively.[57,74] Renal function may also be directly suppressed as it is heated above its critical threshold inducing acute renal failure that is exacerbated by sustained hypotension, crystallization of myoglobin, disseminated intravascular coagulation, and metabolic acidosis associated with exercise.[57,75,76]

There are a multitude of factors that could predispose one to experience uncompensable heat stress including exercising in an environment with a wet bulb globe temperature exceeding 28°C,[57-60] inadequate fitness, incomplete heat acclimatization, or temporary influences such as viral illness or medications.[59,61] Other factors, both

individually or in a combination, can also predispose an individual to uncompensable

heat stress and are included in Table 2.

Table 2. Predisposing Factors to Uncompensable Heat Stress[2,3,57,61,62]

Host Factors	Environmental Factors	Organizational Factors
• Sleep deprivation • Skin disease • Sunburn • Alcohol use • Drug abuse • Antidepressant medications • Obesity • Age >40 years old • Genetic predisposition to malignant hyperthermia • History of heat illness	• Long initial exposure to heat during exercise	• Sudden increase in physical training • Vapor barrier protective clothing • Inadequate hydration • Poor Nutrition

Additionally, during uncompensable heat stress, exercise performance is

drastically reduced mainly due to severe increases in internal body temperature. Once the

internal organ tissue temperature rises above critical levels, cell membranes are damaged

and cell energy systems become disrupted.[57,72] Once the cell is exposed to a temperature

above the critical level, a cascade of events occurs disrupting cell volume, metabolism,

acid-base balance, and membrane permeability initially leading to cell and organ

dysfunction and eventually cell death and organ failure.[57,73]

ii. Sleep deprivation

Sleep deprivation, as well as existing illness, inadequate physical fitness, and

improper acclimation to the environment all fall under physiologic (host) factors

predisposing an individual to uncompensable heat stress according to Mindard's

paradigm.[63,64] In particular, sleep deprivation has been shown to have a minor effect on

physical performance and a considerable effect on decision making and cognitive performance.[65] Physical performance is also decreased considerably without adequate sleep especially in the heat.[65-67] One recent study[68] showed that 30 hours of sleep deprivation had a negative effect on the total distance walked on a treadmill in 30 minutes due to increased metabolic heat strain.

Additionally, one night of sleep deprivation decreased endurance performance with limited effect on pacing, cardiorespiratory, and thermoregulatory function.[68] Daanen et al. studied the subjective ratings of performance in the heat after sleep deprivation.[65] They concluded that subjective estimates of performance are not in line with actual performance for endurance exercise after sleep deprivation and for explosive exercise in the heat.[65] This study fell in line with observations in the literature,[66] which found that power output and aerobic exercise was compromised in the heat during sleep deprevation.[65]

A few explanations have been theorized to account for the loss of performance due to sleep deprivation.[69-71] First, sleep deprivation decreases skin blood flow and sweat rate during exercise at a given body temperature leading to an increase in heat strain.[71] Sleep deprivation may also cause changes in cortisol levels or decreases in growth hormone, which may play a role in temperature regulation and subsequent heat strain.[70] Further research is required to fully understand the associations with sleep deprivation and its effects on performance in the heat.

iii. Heat acclimatization induced adaptations

Decreases in performance due to the above responses can be mitigated through proper heat acclimatization. Exercise heat exposure produces progressive changes in

thermoregulation that are specific to the stress imposed on the body, as shown in Table 3.[2,80] For example, passive exposure to heat induces only some physiological responses (e.g., improved heat dissipation); however, with heat acclimatization through strenuous exercise and heat exposure provides a greater effect than exercise alone in a cool, dry environment.[80] Adequate heat acclimatization requires between 10-14 days, but maximum acclimatization may take up to 2-3 months.[2,80-82]

Table 3. Heat Acclimatization Adaptations Over 14 Days[80]

Physiological Reponses	No Exercise Hot Conditions	Exercise Cool Conditions	Exercise Hot Conditions
Lower core temperature at the onset of sweating	++	+	++
Increased heat loss via radiation & convection (skin blood flow)	++	++	++
Increased plasma volume	+	+	++
Decreased heart rate	⊘	++	++
Decreased core body temperature	++	+	++
Decreased skin temperature	+	+	+
Altered metabolic fuel utilization	⊘	++	++
Increased sympathetic nervous system outflow (efferent)	+	++	++
Increased oxygen consumption	⊘	++	++
Improved exercise economy	⊘	⊘	+
Adaptation to exercise in a cool environment	⊘	++	++
Adaptation to exercise in a hot environment	+	+	++

++ major effect, + moderate effect, ⊘ minimal effect

Although the onset and decay of acclimatization adaptations have individual differences,[2,80,81,83] early adaptations (i.e., initial 1-5 days) show improved control of cardiovascular function, such as plasma volume expansion, HR reduction, and autonomic nervous system habituation that leads to increased blood flow to skin capillary beds and active muscles.[80] During these initial stages of heat acclimatization, proper fluid replacement,[84,85] as well as increases in sodium intake may optimize the adaptation process.[2] The increase in plasma volume from both heat acclimatization and proper fluid

replacement induces a 15%-25% decrease in HR, and with this reduction in cardiovascular strain, an individual's perceived exertion decreases.[80] This increase in plasma volume, however, is a temporary phenomenon (i.e., decays at 8-14 days), and is replaced by a longer-lasting reduction in skin blood flow, increasing central blood volume.[80]

At days 5 to 8 of heat acclimatization, thermoregulatory adaptations (e.g., increased sweat rate, earlier onset of sweat production) are at their maximum, especially when coupled with the improved cardiovascular control in the initial days of heat acclimatization, which induces decreased central body temperature.[80] In addition, on days 3 to 9, the body starts to conserve sodium chloride, which results in an expanded extracellular fluid volume.[80]

Just as heat acclimatization adaptations are induced gradually during exercise in the heat, it can also be lost gradually when heat stress during exercise is no longer present, or an individual becomes inactive. Physiological adaptations from heat acclimatization begin to decay after just six days,[2,86] and adaptations may decay completely after a few weeks of inactivity (i.e., 18-28 days). [80] One of the first physiological adaptations to decay is the cardiovascular adaptations (e.g., HR, stroke volume, etc.). [80] As with heat acclimatization, the rate of acclimatization decay is effected by multiple factors including: (1) the number of heat exposures per week, (2) the number and format of training sessions, and (3) the degree to which core body temperature is elevated.[80,87] Cardiorespiratory fitness also comes into play, as individuals with a higher VO_2max will decay slower than those with a lower VO_2max.

iv. Factors that affect heat acclimatization

There are many factors that influence the capacity to acclimatize to the heat, some of the most common factors being age and gender differences. However, recent research has started to reverse these viewpoints.[80] It is now recognized that few gender-related differences exist when female and male subjects are matched for pertinent physical and morphological characteristics.[80] Researchers have also suggested that differences between older and younger subjects may not be due to age, but due to other factors such as decreased training volume and lower VO_2max.[80] VO_2max and overall fitness status of an individual will influence physiologic responses during the development of heat acclimatization.[2,80] Individuals with a high VO_2max (>60 ml·kg^{-1}·min^{-1}) exhibited superior HR and rectal temperature responses, and usually reach a stable heat acclimatization state faster, when compared to those with a low VO_2max (< 40 ml·kg^{-1}·min^{-1}).[80] Conversely, many experts agree that increased exercise capacity gained from training in a cooler environment will carry over to exercise capacity in the heat, which will assist in increasing the speed of heat acclimatization in people with higher fitness levels.[1,80,88] For example, one may partake in interval training or continuous exercise at an intensity above 50% VO_2max to maintain elevated internal body temperature for 8 to 12 weeks to prevent decay and promote heat acclimatization.

Lastly, illnesses such as cardiovascular disease or history of heatstroke may hinder and/or have the inability to develop physiologic adaptations seen in normal heat acclimatization,[80] known as heat intolerance. An individual exhibiting heat intolerance may not show the classic decreases in HR and rectal temperature as seen in normal individuals during heat acclimatization,[80] however, one researcher[61] discovered that in the

case of individuals who suffered EHS, naturally they would normally regain heat

acclimatization physiologic adaptations 61 days after the initial diagnosis.

HEAT STRESS SCORE

Previous literature[46] utilized a heat stress score (HSS) in an effort to quantify the

amount of environmental heat exposure experienced by runners during exercise. The HSS

score was calculated by the following equation for each exercise bout:

$$\textbf{HSS = Ambient Temperature (°C) x Exercise Duration (min)}$$

Researchers then calculated the average HSS (HSS_T) for a given period by

utilizing the following equation:

$$\textbf{HHS}_T = \frac{\textbf{Ambient Temperature (°C) x Exercise Duration (min)}}{\textbf{Number of Workouts}}$$

Next, in order to compare the exposure experienced during 14 days of training

immediately prior to race day, researchers calculated an Event HSS (HSS_E) and a Ratio

(HSS_R).

$$\textbf{HSS}_E \textbf{ = Race Day Temperature (°C) x Race Time (min)}$$

$$\textbf{HSS}_R \textbf{ = HSS}_E \textbf{ / HSS}_T$$

The HSS_R was defined as, "A ratio between the product of race day temperature

(°C) and race time (minutes), and the mean product of environmental temperature during

the outdoor workouts (°C) and the exercise duration (minutes) reported during the 14

days leading up to the race."[46]

This HHS_R was then categorized into two groups: (1) <1 race day prepared and

(2) >1 not race day prepared. Researchers found there were significant correlations

between HSS and finish time (r=0.626, P<0.01) and relative performance (r=0.505,

P<0.003); however, HSS did not exhibit correlations with post-race rectal temperature (r=0.20, P<0.918) and post-race HR (r=0.132, P<0.528).

GAPS IN HSS LITERATURE

Although the process and benefits of heat acclimatization have been established in previous literature, only one study has attempted to establish the degree of heat exposure required to induce heat acclimatization in preparation for an outdoor warm weather race in a field setting. Several indices have been created to quantify physiological strain during exercise, including the physiological strain index (PSI) and the Heat Strain Index (HSI).[89,90] Both PSI and HSI evaluates heat stress in an exercising individual by utilizing rectal temperature and HR. However, neither account for the amount of heat exposure an individual experienced, which could have a significant impact on how one may respond to physiological strain in the heat. The original HSS attempted to quantify heat exposure, however, the equation failed to quantify exercise intensity and physiological strain imposed to the person relative to their fitness level. Thus, by combining relative physiological strain and environmental heat exposure, a more accurate representation of heat acclimatization status and amount of heat exposure required to achieve optimal performance may be obtained.

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II. INTRODUCTION

Heat acclimatization is the process by which physiological adaptations occur when an individual is gradually exposed to heat and intensity through exercise and physical activity.[1] Previous literature has shown that heat acclimatization increased preparedness to perform in the heat.[2-4] Performance in the heat can also be augmented by increased physical fitness. For example, habitual exercise, specifically running, is known to improve and maintain wellness and physical fitness in the general population. Running provides numerous benefits such as higher VO_2max, improved body temperature control, higher stroke volume, greater skin blood flow, and higher sweat rates.[5] However, when one fails to properly heat acclimatize, it can place the individual at greater risk for exertional heat illness (EHI) and decreased performance due to the increased cardiovascular strain from the heat. When the heat strain and lack of heat acclimatization impose uncompensable heat stress on the body, the athlete is at risk for exertional heat stroke (EHS).

One race known to have a high incidence of EHS is the Falmouth Road Race (FRR) in Falmouth, MA. The overall incidence rate of two EHS cases per 1000 finishers was reported by Brodeur et al.[6] This incidence rate is ten times higher than the Twin Cities Marathon, which has an incidence rate of one to two EHS cases per 10,000 finishers.[7] The FRR is held in mid-August every year, with thousands of participants with experience levels ranging from elite to novice. The race is also unique in its distance of 11.2km (7-miles). The FRR is considered a mid-distance race, although it's short enough to elicit maximum intensity performance for the 7-miles creating the perfect storm to increase internal body temperature. Due to this high incidence rate of EHS, further

research is warranted to investigate how runners are preparing before the race in an attempt to mitigate heat related illness.

Torres[8] attempted to investigate the amount of heat exposure required to optimize the race performance in an outdoor warm weather race utilizing a Heat Stress Score (HSS). This HSS, however, was not associated with hallmark adaptations observed in heat acclimatization such as rectal temperature (T_{rec}) and heart rate (HR). For the layperson preparing for a warm weather race, taking a T_{rec} is not always feasible. Furthermore, although HR measure may be more practical, there currently is no index that assesses one's heat acclimatization status using HR. Therefore, this study aimed to examine race preparedness by utilizing a modified HSS during the four weeks prior to a warm weather race, which quantifies exercise heat exposure and physiological strain (e.g., T_{rec}, HR) combined. In addition, the modified HSS was compared with runner's perceptual (e.g., thirst sensation, thermal sensation, rating of perceived exertion [RPE]), hydration status, and modified environmental symptoms questionnaire (ESQ) measures.

III. METHODS

Study Overview

All participants completed preliminary fitness testing at the University of Connecticut's Human Performance Laboratory. Race day data collection occurred at the FRR in Falmouth, MA on August 16, 2015. The FRR is an 11.2 km (7-mile) point-to-point race, with a 9am race start time. Participants presented for data collection pre-race and post-race. The University of Connecticut Institutional Review Board approved this study.

Participant Enrollment

A multiple linear regression analysis with 0.05 alpha level, effect size of 0.5, desired power level of 0.8, and the number of predictors at three (i.e., age, prior heat exposure, cardiovascular fitness level), researchers estimated (G*power 3.1) a recruitment size of n=19 participants. Runners registered for the 2015 FRR were recruited via email and poster flyers. Inclusion criteria were as follows: (1) age between 18 and 65, (2) registered for the 2015 FRR, (3) no chronic health problems, (4) no history of cardiovascular, metabolic, or respiratory disease, (5) no fever or other current illness at the time of the race, (6) predicted to finish the race in 60 minutes, (7) no current musculoskeletal injury that limited physical activity, and (8) a negative pregnancy test (female only) on the day of fitness testing and the race.

Once an interested participant met all inclusion criteria, participants were contacted via email or phone by investigators to hold an informed consent session. The informed consent session provided information regarding the research objectives, procedures, study completion incentives, and risks and benefits associated with the study. In addition, the eligibility criteria were confirmed for subject safety and consistency in recruitment. After the investigators had informed consent, an email with a medical history questionnaire, a training history questionnaire, a menstrual history questionnaire (female only), and a study consent form. 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 participants: (1) submitted a signed consent form, (2) submitted a training history questionnaire, (3) submitted a

menstrual history questionnaire (females only), and (4) were medically cleared by our physician to participate in the study. The investigators stopped recruitment once the number of enrolled participants reached 36. Due to various reasons five participants (n=1 male, n=4 females) withdrew from the study, and 17 participants (n=9 males, n=8 females) were excluded from final data analysis. Final participant enrollment was 14. A sample of anthropometric and performance variables for included participants are presented in table 1.

Table 1. Participant Demographic and Anthropometric Variables

Variable	Participants (n=14)*
Age	39 ± 11 years
Height	174.12 ± 9.26 cm
Body Mass	67 ± 8.45 kg
Body Fat	16.94 ± 4.58 %
Body Mass Index	22.05 ± 1.62 kg/m^2

*Mean ± SD; **n=13

Data Collection Prior to the Falmouth Road Race
Daily Training Log

Each participant received a subject number and individual link to an online training log that was created for this study (REDCap [Research Electronic Data Capture]). Participants logged their daily exercise data leading up to the 2015 FRR. This training log started 28 days prior to race day, and in order to be included in the analysis participants were required to log in and complete at least 25 out of 28 days. The online training log was consisted of 13 questions related to their general health and training, and can be found in table 2.

Table 2. Online Daily Training Log 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?
(4) Did you take any medication and/or supplements not reported in the medical history questionnaire?
(5) Please select the start time of your workout.
(6) What was your average heart rate?
(7) Please rate you level of perceived exertion immediately after the workout
(8a) Where did the workout take place? (city/state)
(8b) Where did the workout take place? (zip-code)
(9) Choose your workout venue.
(10) Please select the type of workout you completed.
(11) Please log the distance you completed (if applicable; run, bike, swim).
(12) What was your total exercise time? (minutes)
(13) Did you use speed (pace) or intensity (heart rate) to guide your workout today?

Maximal Oxygen Consumption and Lactate Threshold Testing

Participants arrived at the Human Performance Laboratory at the University of Connecticut, Storrs, to participate in maximum oxygen consumption (VO_2max) and lactate threshold (LT) testing approximately two weeks prior to race day. During this visit, investigators collected body composition, height, body mass, HR, RPE score, urine specific gravity (USG), urine color, and conducted pregnancy test for females. The body composition was measured using 3-site skinfold measurements (Lange Skinfold Calipers, Santa Cruz, CA).[9] Chest, abdomen, and anterior thigh, were used for male participants, and triceps, suprailiac, and anterior thigh were used for female participants.

Measurements were taken two times per site, and the average was used for calculation. A third measurement was taken if the first two measurements were separated by more than 2mm.

After providing a urine sample, participant's hydration status was analyzed via refractometer (Model A 300 CL, A. Daigger & Company, Lincolnshire, IL). Participants with USG ≥1.020 were given 500ml of water before testing to ensure they were euhydrated. The participants were also familiarized with the disposable rectal probe and thermometer (DataThermII, RG Medical Diagnostics, Southfield MI), Global Positioning System (GPS) watch, and HR monitor (IRONMAN Run Trainer 1.0, Timex Group USA, Middlebury, CT).

First, researchers conducted VO_2max testing to determine participant's aerobic capacity. Participants warmed up for five minutes on the treadmill at a self-selected pace, while researchers explained testing procedures. Once the participant was ready, testing began using a metabolic cart (model CPX/D, Medical Graphics Corporation, St. Paul, MN) to capture respiratory gases. Stages consisted of three minutes running at a given intensity with a 1% treadmill grade. Treadmill speed was set at 75% of the participant's reported 5-kilometer run pace, and was increased by 0.5 miles per hour (mph) every three minutes. Additionally, the participants reported their RPE and were asked if they would like to continue to the next stage every three minutes. Measures for a complete test included having met at least two of the following criteria: (1) resting exchange ratio of ≥1.1, (2) HR within 10 beats per minute of predicted maximum HR, (3) having a RPE >19, and (4) reached volitional exhaustion.

After the participants completed VO_2max testing, they rested for 30 minutes

before conducting the LT test to determine their anaerobic threshold. Participants warmed up for five minutes at a self-selected pace while researchers explained study procedures. Immediately post warm-up, an initial finger-prick lactate measurement was obtained and analyzed using a handheld lactate meter (Lactate Plus, nova biomedical, Waltham, MA). Once the participant was ready, testing began with the treadmill speed set at 70% of the participant's velocity at VO_2max. Stages consisted of three minutes running at the given intensity with a 1% treadmill grade. Every three minutes, upon participant's approval, treadmill speed was increased by 0.5 mph and RPE was self-reported. Following each stage, subjects straddled the treadmill for one minute to allow for collection of a finger-prick blood sample to measure lactate. A lactate reading of 4 mmol/L or greater for two consecutive stages was set as a completed test.

Three Days Leading Up to the Race Day

Researchers asked participants to refrain from strenuous exercise (any exercise load and intensity that is more than the participant's usual routine) and intake of alcoholic beverages.

Data Collection at Falmouth Road Race

Race Day Pre-Race Data Collection

Participants met the research team pre-race where researchers collected body mass, rectal temperature, urine color, urine specific gravity, morning dietary intake log, ESQ, thermal sensation, thirst sensation, and RPE perceptual measures. 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. Rectal

temperature was recorded using a handheld device (DataThermII, RG Medical Diagnostics, Southfield MI) upon arrival to the research tent. Insertion of 10cm beyond the anal sphincter was criteria for inserting the disposable rectal probe. Participants also answered four different perceptual scales: thermal and thirst sensation, ESQ, and RPE. The thermal sensation scale is an eight point validated scale in 0.5 increments examining perceived thermal (hot/cold) sensations.[10] The thirst sensation scale is a nine point validated scale with one point increments examining perceived thirst levels,[10] The ESQ is a 33 question validated scale reflecting environmental symptoms,[11-12] and the RPE scale is a 14 point validated scale with one point increments examining perceived exertion.[13] Lastly, the participants were fitted with a GPS watch and a HR monitor strap, which collected the run time, pace, distance, and HR.

Race Day Post-Race Data Collection

Participants were instructed to check-in at the research tent immediately after finishing the race. Rectal temperature was measured upon arrival to ensure participant's safety and screen for risk of EHS. Each participant was then guided to a designated portable bathroom with a disposable rectal thermometer and a urine sample cup. Participants' body mass was measured before collecting the urine sample to keep measurement consistent with pre-race data collection. Once the T_{rec} was measured and the urine sample was collected, participants were instructed to sit in a chair under a covered research tent for 30 minutes. Heart rate, ESQ, thermal sensation, thirst sensation, and RPE perceptual measures 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 and their VO$_2$max (VDOT) predicted FT (Equation 1 & 2):

Equation 1

% Off Predicted FT = [(Actual FT-Predicted FT)/ Predicted FT]*100

Equation 2

% Off VDOT Predicted FT=[(Actual FT-VDOT Predicted FT)/VDOT Predicted FT]*100

Race Day 30-minutes Post-Race Data Collection

After 30 minutes post-race, T_{rec}, ESQ, thermal sensation, thirst sensation, and RPE perceptual measures were completed before participants' release from the research tent.

Weather Data

Weather data (e.g., ambient temperature [T_{amb}], relative humidity [RH]) on race day were obtained using Weather Underground© (wunderground.com / software VWS V15.00). The station utilized was Falmouth Village (weather station ID: KMAFALMO7) for hourly race day weather data collection. The same methodology was used to calculate the weather variables of each participant's daily training location via zip code, which were obtained from the pre-race training log. Participant's self-reported zip code was entered into the software and hourly weather status was located for the specific time and day the participant exercised during training to maximize weather data validity. Table 3 presents a data collection timeline for all variables collected in the study.

Table 3. Data Collection Timeline

Variable	≤4 Weeks Pre Race Pre	VO$_2$max Testing	Pre Race	During Race	Post Race
Training Log and Records					
Online Training Log					
Menstrual Status (Females)		X	X		
Anthropometric and Physiological Variables					
Body Composition		X			
Height		X			
Body Mass		X	X		X
Heart Rate	X	X	X	X	X
T$_{rec}$			X		X
VO$_2$max		X			
Questionnaires and Perceptual Scales					
Thermal Sensation			X		X
Thirst Sensation			X		X
ESQ			X		X
RPE	X	X	X		X
Performance Variables					
GPS				X	
Finish Time					X
Environmental Conditions					
WBGT		X	X	X	X
Ambient Temperature	X	X	X	X	X
Relative Humidity	X	X	X	X	X
Heat Index	X	X	X	X	X
Biological Sample Collections					
USG		X	X		X
Urine Color		X	X		X
Pregnancy Test (Females)		X	X		

T$_{rec}$, rectal temperature.
ESQ, environmental symptoms questionnaire.
RPE, rating of perceived exertion.

GPS, global positioning system.
WBGT, wet bulb globe temperature.
USG, urine specific gravity.

Heat Stress Score

In an effort to quantify the amount of environmental heat exposure experienced by each participant we calculated each individual's total HSS during training (HSS_T) (Equation 3). The HSS for the race day (HSS_R) was also calculated to determine environmental heat exposure during competition (Equation 4). Since race day temperature was 25°C, 25 was utilized in the equation to quantify race day heat exposure.

Equation 3

Heat Stress Score (HSS_T) = Ambient Temp (°C) x Exercise Duration (min)

Equation 4

Heat Stress Score Event (HSS_R) = FT x 25

Additionally, physiological strain was calculated for race day and exercises completed in the 28 days prior to race day by calculating Edward's Training Impulse ($TRIMP_T$) scores (Equation 5). The formula for calculating TRIMP scores is as follows:

Equation 5

Edward's TRIMP Score ($TRIMP_T$) = t x y

t = exercise duration (min)

y = VO$_2$max average HR weighting factor

Table 4. VO$_2$max HR Weighting Factor

VO$_2$max Heart Rate	50%-60%	60%-70%	70%-80%	80%-90%	90%-100%
Score	1	2	3	4	5

The VO$_2$max HR weighting factor was based off of heart rate zones as shown in table 4. Each exercise bout was given a weighted score of 1-5 based on their level of exertion during their training exercise. Race day exertion was also calculated using the same method (**TRIMP$_R$** [Equation 6]). Due to all participants obtaining a score of 5 on the Edward's TRIMP HR weighting scale, the calculation for TRIMP$_R$ utilized 5 as the race day HR weighting factor. Once TRIMP was calculated, the average scores were combined with the average HSS$_T$ and HSS$_R$ in a modified Physiological Strain Index to quantify heat exposure as well as physiological strain to create an updated HSS via the following weighted calculation (Equation 7):

Equation 6

$$\textbf{TRIMP}_R = FT \times 5$$

Equation 7

$$\textbf{HSS} = 2\,(HSS_T / HSS_R) + 1\,(TRIMP_T / TRIMP_R)$$

Statistical analysis via regression showed that the HSS accounted for twice the amount of variance explained in FT compared to exercise intensity, so the equation was weighted 2:1. This number is arbitrary at the moment, as more research needs to be conducted to validate these numbers.

Performance Variables

The chip FT collected by the FRR was used for race finish times. Relative performance was also measured by calculating percent off predicted pace, as seen in equation one above. This was used to predict if a participant successfully predicted their pace and if they were able to maintain their pace throughout the race.

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Statistical Analysis

The purpose of this research was to investigate if the HSS equation is improved by integrating the magnitude of exercise intensity in addition to the amount of heat exposure during exercise, as well as if the HSS was correlated to perceptual (e.g., thirst sensation, thermal sensation, RPE), hydration, and ESQ measures. Parametric statistics were used in a Pearson product correlational analysis to identify significant differences between variables. Additionally, part and partial correlation via linear regression was used to analyze those variables showing clinical significance. The significance level was set *a priori* at $p<0.05$. All data were analyzed using SPSS version 21.0 (IBM Corporation, Champaign, IL, USA).

IV. RESULTS

Online Daily Training Log

The participants logged a total average of 25.93 ± 8.88 workouts over the 28 days, with an average of 12.29 ± 5.62 workouts the four weeks immediately pre-race, and an average of 13.64 ± 5.51 workouts two weeks immediately pre-race. The total average workout duration was 49.61 ± 14.21 minutes, with an average of 54.26 ± 17.23 minutes and 46.51 ± 13.00 minutes for the four weeks and two weeks immediately pre-race, respectively. Total average T_{amb} during training was $21.64 \pm 4.29°C$, with an average of $22.72 \pm 7.09°C$ and $21.12 \pm 3.98°C$ for the four weeks and two weeks immediately pre-race, respectively. Additionally, total average RH was 54.54 ± 8.14 %, with an average RH of 57.73 ± 11.17 % and 53.54 ± 12.58 % for the four weeks and two weeks immediately pre-race, respectively.

Race Day

Participants had an average FT of 56.07 ± 9.28 minutes, with the fastest and slowest FT reported as 78 minutes and 41 minutes, respectively. The average temperature (25.8 ± 1.51°C) and RH (66.8 ± 4.92 %) were calculated for the duration of time it took for the participants to finish the FRR (9:00am – 10:18am).

Performance Variables

The average HSS was 2.58 ± 0.20, with an average FT of 56.07 ± 9.28 minutes (Table 5). A higher average HSS resulted in a faster self-predicted FT (r=-0.56, R^2=0.32, P=0.046 [Figure 1]), and showed moderate associations with participant's FT and VDOT predicted FT respectively (r=-0.45, R^2=0.20, P=0.104; r=-0.39, R^2=0.15, P=0.171). The average HSS, VO_2max, and speed at LT when combined predicted 92% of the variance observed in FT (r=0.96, R^2=0.92, P<0.001). Alone, VO_2max predicted 86% and speed at LT predicted 75% of the variance in FT, respectively (r=0.93, R^2=0.86, P<0.001; r=0.87, R^2=0.75, P<0.001).

Furthermore, a slower self-predicted FT was significantly correlated with a slower FT (r=0.64, R^2=0.40, P=0.020), and a slower VDOT predicted FT was significantly correlated with a slower FT (r=0.93, R^2=0.87, P<0.001).

F igure 1. Displays the average HSS correlation during training with participants' pre-race self-reported FT. Researchers concluded that as the average HSS decreased during training indicating less exercise heat exposure and exercise intensity, the self-reported predicted FT increases. R^2=0.32, P=0.046.

Table 5. Performance Variables

Variable	Participants n=14*
FT	56.07 ± 9.28 min
VO₂Max	51.05 ± 6.33 ml˙kg˙min
Speed at LT	8.77 ± 1.05 mph**
Average HSS	2.58 ± 0.20
Self-Predicted FT	53.15 ± 8.44 min**
VDOT-Predicted FT	46.88 ± 5.74 min
Percent Off Self-Predicted FT	4.34 ± 12.32 min**
Percent Off VDOT-Predicted FT	18.99 ± 8.50 min

*Mean ± SD; **n=13; HSS, heat stress score; FT, finish time; VDOT, VO₂max; LT, lactate threshold

Anthropometric and Physiological Variables

Participants' average VO_2max HR was 174.14 ± 12.99 bpm, and their average HR during training was 140.57 ± 12.94 bpm (Table 6). A higher average HSS had a statistically significant correlation resulting in a lower VO_2max HR (r=-0.56, R^2=0.31, P=0.039 [Figure 2]); however, average HSS was not significantly correlated to average training HR and average race day HR respectively (r=0.25, R^2=0.06, P=0.399; r=-0.09, R^2=0.01, P=0.755). Additionally, a higher HSS did not result in a lower T_{rec} post race (r=-0.30, R^2=0.09, P=0.298).

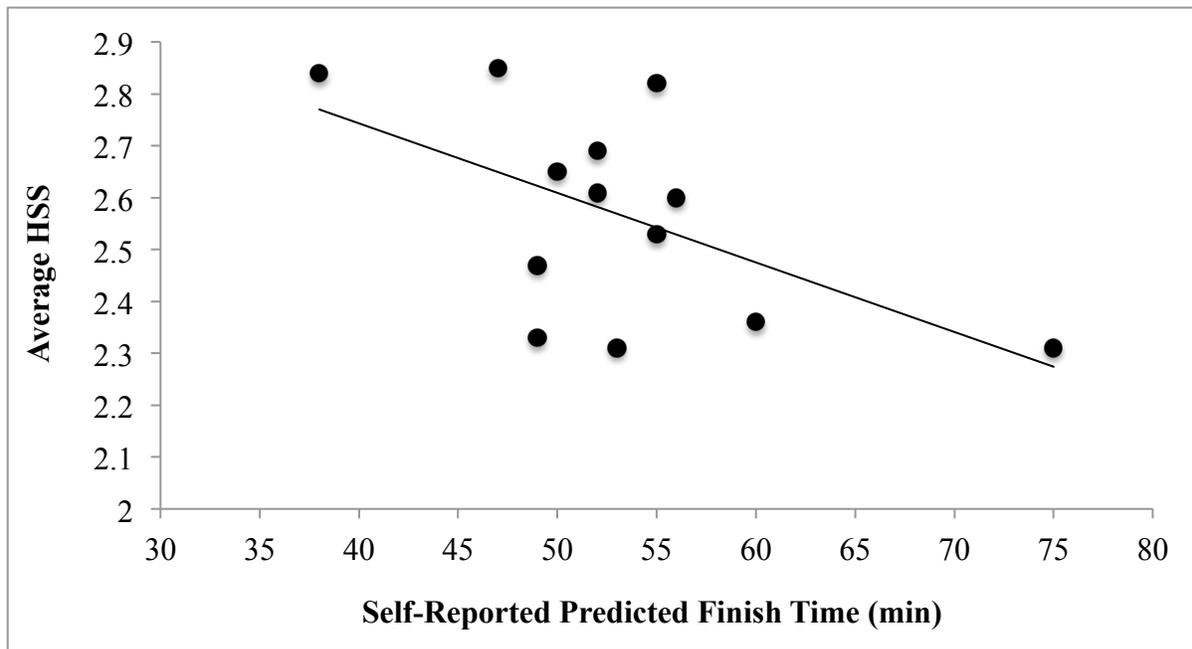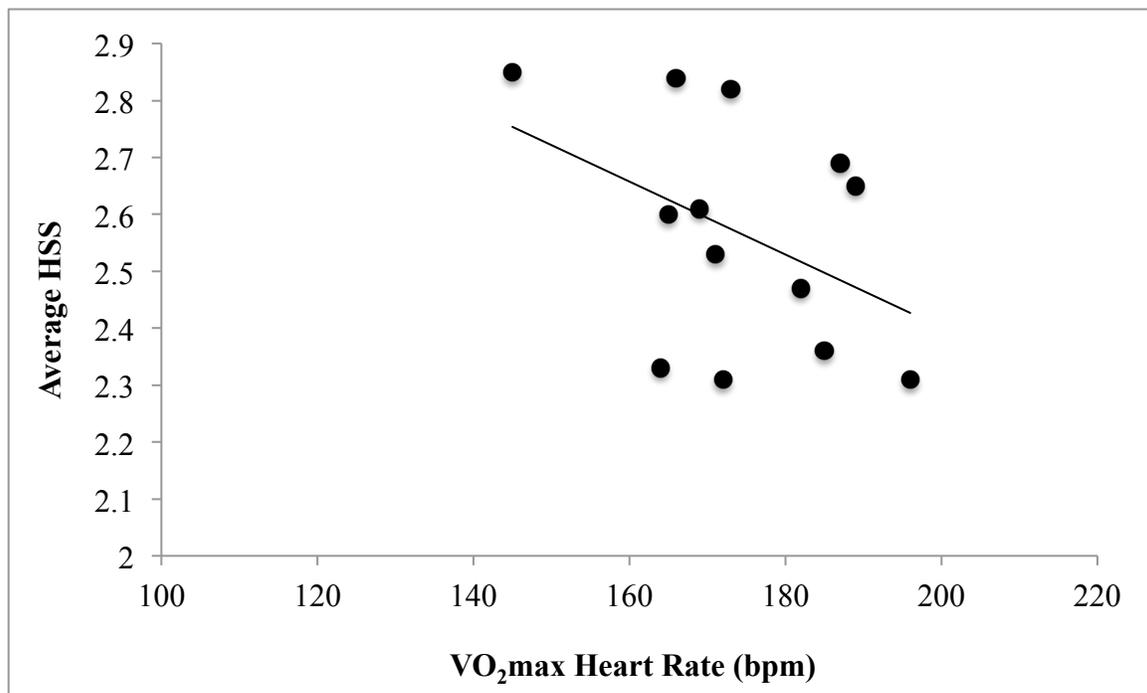**Figure 2. Displays the average HSS correlation during training with participants' VO_2max HR. Researchers concluded that as the average HSS decreases during training, indicating less exercise heat exposure and exercise intensity, participants' VO_2max HR increases. R^2=0.31, P=0.039.**

Furthermore, an increased training average HR was significantly correlated with an increased average HR during race day (r=0.57, R^2=0.32, P=0.034), and a higher training average HR was associated with a higher average training RPE (r=0.50, R^2=0.25, P=0.071). An increased VO_2max HR was significantly correlated with a higher average

HR during race day (r=0.56, R^2=0.31, P=0.038), and increased body fat was significantly correlated with a slower change in T_{rec} from post to post 30-minutes (r=-0.59, R^2=0.35, P=0.027).

Table 6. Physiological Variables

Variables	Participants n=14*
Average VO$_2$max HR	174.14 ± 12.99 bpm
Average Training HR	140.57 ± 12.94 bpm
Average HR Post-Race	170 ± 8.82 bpm
T_{rec} Pre-Race	37.01 ± 0.39 °C
T_{rec} Post-Race	39.82 ± 0.47 °C
T_{rec} 30min Post-Race	37.70 ± 0.36 °C

*Mean ± SD; HR, heart rate; T_{rec}, rectal temperature

Environmental Symptoms Questionnaire and Perceptual Variables

The ESQ scores post-race were 3.79 ± 2.20, with RPE scores post-race equating to 17.07 ± 1.82 (Table 7). During training, average RPE scores were 13.14 ± 1.03. The total HSS did not correlate with any ESQ or perceptual variables. A higher average training RPE showed a statistically significant correlation resulting in a lower T_{rec} 30-minutes post race (r=-0.58, R^2=0.33, P=0.032 [Figure 3]), and an increased thirst sensation post race showed a statistically significant correlation with an increased average HR on race day (r=0.65, R^2=0.42, P=0.012).

Furthermore, a higher ESQ score post race presented with a statistically significant correlation to an increased average HR on race day (r=0.61, R^2=0.38, P=0.020). Additionally, a higher ESQ score post-race showed statistical significance with

a higher average HR during training ($r=0.53$, $R^2=0.28$, $P=0.050$). An increased ESQ score 30-minutes post race showed statistically significant correlations resulting in a higher FT ($r=0.59$, $R^2=0.35$, $P=0.027$), a higher self-predicted FT ($r=0.64$, $R^2=0.41$, $P=0.019$), and a higher VDOT predicted FT ($r=0.56$, $R^2=0.31$, $P=0.037$).

Avergae Training RPE (y-axis: 8, 9, 10, 11, 12, 13, 14, 15, 16)

T_{rec} 30 min Post-Race (x-axis: 37.20, 37.40, 37.60, 37.80, 38.00, 38.20, 38.40, 38.60, 38.80)
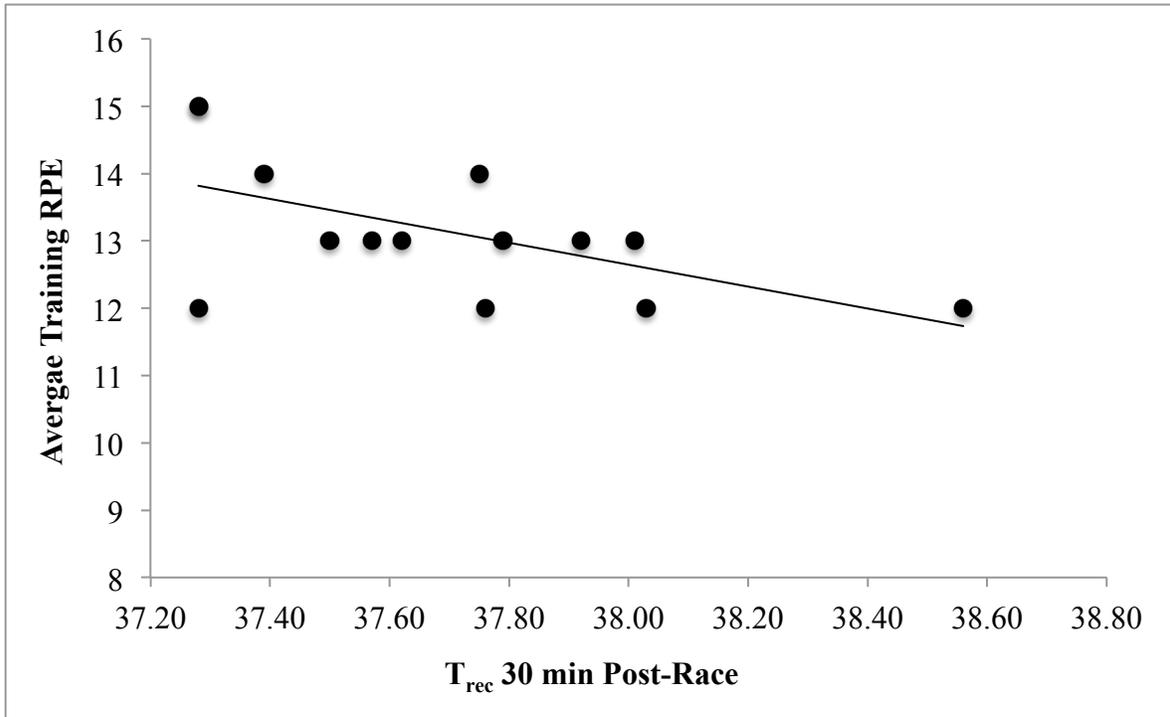
Figure 3. Displays the correlation between T_{rec} 30 min post-race with the average training RPE. Researchers concluded that as the average training RPE decreased indicating lower exercise intensity, T_{rec} 30 min post-race increased. $R^2=0.33$, $P=0.032$.

Table 7. Perceptual Variables

Variable	Participant n=14*
ESQ Pre-Race	3.07 ± 2.13
ESQ Post-Race	3.79 ± 2.20
ESQ 30min Post-Race	3.79 ± 2.20
Thermal Sensation Pre-Race	4.18 ± 0.70
Thermal Sensation Post-Race	6.11 ± 1.35
Thermal Sensation 30min Post-Race	3.54 ± 0.63**
Thirst Sensation Pre-Race	3.21 ± 1.53
Thirst Sensation Post-Race	6.21 ± 1.20
Thirst Sensation 30min Post-Race	3.77 ± 1.36**
Average Training RPE	13.14 ± 1.03
RPE Pre-Race	6.43 ± 0.85
RPE Post-Race	17.07 ± 1.82

*Mean ± SD; **n=13; ESQ, environmental symptoms questionnaire; RPE, rating of perceived exertion

Hydration Variables

Average urine color post-race was 2.29 ± 1.20, with the percent body weight lost between pre- and post-race being 1.23 ± 0.67 % (Table 8). No statistically significant correlations were found between the HSS and the biological variables (e.g., USG and urine color). There were statistically significant correlations between decreased average sleep during training resulting in a decreased USG post race (r=0.64, R^2=0.41, P=0.014).

Table 8. Hydration Variables

Variable	Participant n=14*
Urine Color Pre-Race	3.43 ± 1.60
Urine Color Post-Race	2.29 ± 1.20
USG Pre-Race	1.013 ± 0.008
USG Post-Race	1.008 ± 0.005
Body Weight Change Pre-Post	-0.66 ± 0.64 kg
Percent Body Weight Lost	1.23 ± 0.67 %

*Mean ± SD; USG, urine specific gravity

V. DISCUSSION

Previous literature has shown that heat acclimatization adaptations increase an individual's preparedness to perform in the heat,[2-4] and by failing to properly heat acclimatize, it can place an individual at greater risk for EHI and have decrements on their exercise performance. Complete heat acclimatization requires between 7-14 days of exercise heat exposure, however, maximum acclimatization may take up to 2-3 months.[1,2,18,19] Adaptations that occur during this time include lower core body temperature at the onset of sweating, increased plasma volume, decreased HR, decreased core body temperature, and improved exercise economy to name a few.[2-4] However, for the untrained layperson in the field preparing for a warm weather race, taking a T_{rec} is not always feasible and there are currently no indices to determine at what HR an individual is properly heat acclimatized.

The previously studied HSS[8] did not correlate with physiological measures such as T_{rec} (r=0.20, P=0.918) and HR (r=0.13, P=0.528) that are used to quantify the heat

acclimatization status of an individual. The updated version of the HSS used in our study found a clinically significant correlation with participant's VO_2max HR (r=-0.56, R^2=0.31, P=0.039); however, the updated HSS was not correlated with average training HR (r=0.25, R^2=0.06, P=0.399) or race day average HR (r=-0.09, R^2=0.01, P=0.755). These findings suggest that an athlete's VO_2max HR is important in quantifying exercise intensity and metabolic heat production. By training based on their VO_2max HR, an individual may be able to better quantify their heat exposure utilizing the HSS in preparation for race day.

There were many differences in the previously studied HSS[8] and the updated HSS researched in this study. First, participant's exercise was studied for 28 days prior to race day, instead of 14 days in the previous study. As previously stated, adequate heat acclimatization requires between 10-14 days, but maximum acclimatization may take up to a few months.[1,2] By extending the range of capturing data to 28 days, this allowed researchers to view a broader range of heat exposure prior to race day in attempts of participants achieving full heat acclimatization adaptations. Additionally, the average HSS_R quantifying heat exposure during training for the previous study[8] was 1.46 ± 0.55, while our average HSS was 2.58 ± 0.20. This indicates that participants on average were exposed to greater heat stress during 28 days versus 14 days; however, this extended exposure still proved to be ineffective at capturing participant's preparedness via the HSS.

Second, average HR and RPE scores were required measures to be taken during each training exercise bout in an attempt to quantify the magnitude of exercise intensity during the 28 days; the previous HSS did not utilize these measures during training. With

the addition of HR and RPE measures during training, researchers were able to supplement exercise heat exposure with exercise intensity into the updated HSS equation; however, this improved methodology still proved to be inadequate in quantifying a participant's preparedness for race day.

Also, the previously studied HSS[8] only quantified exercise heat exposure during training and race day, which produced an average HSS_R of 1.46 ± 0.55. The updated HSS quantifies the magnitude of exercise intensity in addition to the amount of heat exposure experienced during training and race day, resulting in an average HSS of 2.58 ± 0.20. Granted, the previous HSS's[8] participants completed an average of 11.44 ± 3.87 workouts over 14 days compared to our study's average of 25.93 ± 8.88 workouts over 28 days, so our participants should have naturally received more environmental heat exposure resulting in a higher overall HSS. Due to differing mathematical formulas determining the HSS between these two studies, further statistical examination is required to determine if the addition of 14 days proved to be a more effective method of determining exercise heat exposure. Nonetheless, exercise intensity is the number one factor leading to an increased core body temperature[1], thus capturing the magnitude of exercise intensity was an imperative measure to facilitate an improved and more efficacious HSS calculation;[1,14-17] however, the improved methodology in our HSS equation did not prove effective.

When comparing participants between the previously studied HSS[8] and the updated HSS, although the sample size is decreased in our study, the remaining variables (i.e., age, body mass, body fat) remained relatively similar (age=40 ± 11years, body mass=76.3 ± 8.5kg, body fat=$18.6 \pm 5.6\%$; age=39 ± 11 years, body mass=67 ± 8.45 kg,

body fat=16.94 ± 4.58 %, respectively). This suggests that the differences seen in our study compared to the previous study can positively be attributed to the differences in study methodology.

$$(HSS_R = HSS_E / HSS_T)$$

Where...

HSS_E = Race Day Temperature (°C) x Race Time (min)

HHS_T = <u>Ambient Temperature (°C) x Exercise Duration (min)</u>
Number of Workouts

The previously studied HSS[8], as referenced immediately above, found as the HSS increased, a participant's FT was increased (r= 0.626, P<0.01). Our updated average HSS found differing results that showed as average HSS increased, participant's self-predicted FT was decreased (r=-0.56, R^2=0.32, P=0.046). Both equations, however, utilized FT as a multiplication factor possibly leading to bias in the final HSS. This is discussed further in the limitations section of this paper. When combined with VO_2max, the average HSS was a statistically significant predictor of FT and VDOT predicted FT. According to these findings, in order to accurately predict preparedness to run in an outdoor, warm weather race, a participant must know their VO_2max in addition to their exercise intensity and exercise heat exposure. This, however, is not always feasible since conducting VO_2max testing is relatively expensive and not readily available for the average individual preparing for an outdoor race.

Additionally, we found similar results as the previously studied HSS[8] in that the HSS was not correlated with T_{rec} at FT (r=-0.30, R^2=0.09, P=0.298; r=0.20, P=0.918, respectively). Literature[1,4] has shown that the only true methods to determine internal

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temperature during exercise is through the use of a rectal thermometer, esophageal probe, or ingestible thermistor, and this study's results are in line with that literature. Further investigation into improving the accuracy of the HSS as it relates to T_{rec} is needed. Moreover, the original HSS[8] was not correlated with ESQ measures taken on race day (r=0.061, P=0.739). Our updated HSS contrasted these findings by showing as the HSS increased during training, participant's ESQ scores 30-minutes post race decreased (r=-0.40, R^2=0.16, P=0.159). This phenomenon of a decreased ESQ is recognized as a sign of heat acclimatization status, with literature concluding that heat acclimatization decreases the level of perceived exertion while exercising in the heat.[2] Athletes may use this finding to help predict their rate of recovery post-race based on their HSS prior to race day; however, more research is needed to determine the HSS efficacy in relation to ESQ measures.

Lastly, there were no variables (e.g., T_{rec}, sweat rate, etc.) that allowed the researchers to capture if participants successfully reached proper heat acclimatization status during training. It is possible that participants may have experienced heat acclimatization adaptations, such as lower T_{rec}, denoting that their heat acclimatization adaptations enhanced their performance in the heat and on race day. However, because these variables were only taken pre, post, and 30-minutes post on race day, it is difficult to determine the degree of adaptation a participant may have experienced during the 28 days of training prior to race day.

Limitations

During training and race day, maximum HR was not able to be captured due to inadequate equipment, limiting the ability to truly capture exercise intensity. If maximum

HR was captured, researchers could have more accurately calculated the percent VO_2max participants trained in, as well as the percent VO_2max during race day to determine exercise intensity. Additionally, weather data were retrospectively captured via zip codes from an online weather source (Weather Underground©). This method only was able to provide a weather measure from the nearest weather station, instead of a more localized measure the participant may have exercised in. For example, some participants ran in a location with multiple zip codes in a confined area (e.g., New York, Los Angeles), however, only one zip code could be reported.

Furthermore, exercise intensity during training for the 28 days prior to race day was not standardized. Environmental standardization could not be achieved due to participants' geographical location being different, however, if VO_2max was known prior to the start of training, standardized exercise utilizing appropriate percentage of VO_2max and HR zoning could have been achieved to maximize their training. This lack of control simulated realistic training between participants, however, it makes comparing and correlating data difficult due to large differences in training between participants. For example, one participant only completed 12 workouts over 28 days, in comparison to another participant who completed 46 workouts. Additionally, many participants were exercising before the 28 days prior to race day, so effects of exercise bouts outside of the study period were not captured.

Moreover, the study's participant sample size was small (n=14), limiting the application of the HSS to relate to the general population. However, a post-hoc regression power analysis showed that the number of predictors we used (i.e. one) resulted in an effect size of 0.47 with a power of 0.804. Lastly, our HSS equation included FT as a

multiplication factor. Utilizing this methodology could have caused bias in the data, falsely indicating statistical significance. Further evaluation and modification of the HSS equation must be made to decrease the chance of bias in future statistical analysis.

Future Research

Future research may possibly improve the HSS by utilizing Banister's TRIMP[20-25] instead of Edward's TRIMP during HSS calculation. Banister's TRIMP quantifies exercise intensity by calculating the change in HR from pre to post-exercise instead of utilizing the average HR. By utilizing the change in HR from pre to post-exercise, researchers would be able to more accurately capture exercise intensity, and this method guards against long duration, low intensity exercise which would result in a low average HR. Limited HR data (i.e., no maximum HR captured) during the training exercises prevented researchers from utilizing Banister's TRIMP. Researchers have looked at the validity and efficacy of Banister's TRIMP compared to Edward's TRIMP.[22] Average and maximum HR for 10 Taekwondo athletes were recorded and analyzed using a Pearson product moment correlation coefficient to assess the validity between the two methods.[22] Pooled Banister's TRIMP and pooled Edward's TRIMP (pooled data n=284) were largely correlated (r=0.89, P<0.05, 95% CI=0.86-0.91).[22] Researchers concluded that the two methods could be used interchangeably.[22]

Furthermore, a controlled study utilizing an environmental chamber to account for environmental conditions, as well as number of exercises prior to race day, may help to provide validity and efficacy to the use of the HSS. Participants may exercise in the environmental chamber at specific pre-set conditions, and measures of heat acclimatization status (e.g., HR, T_{rec}, VO_2max, sweat rate, etc.) may be taken to assure

proper heat acclimatization has taken place. Although further testing is needed to validate the HSS, it may provide athletes a valuable tool to assess their heat acclimatization status in the field.

Conclusions

The purpose of this study was to investigate if the correlation between previously studied HSS and perceptual (e.g., thirst sensation, thermal sensation, RPE), hydration, and ESQ measures could be improved by the addition of exercise intensity into the heat exposure calculation. In the context of the FRR, the HSS was effective in predicting race day performance via participant's self-predicted FT. When the average HSS was combined with VO_2max values, it was able to further predict participant's preparedness.. No significant correlations were found between HSS and T_{rec} post race, training HR, and race day HR. These findings indicate that the HSS cannot replace T_{rec} and HR in assessing heat acclimatization status, and until further research can validate the HSS, it should not be utilized to accurately assess ones preparedness to participate in an outdoor, warm weather race.

VI. APPENDICIES

Training History Questionnaire

Please fill out the information for any races you've completed, or plan to complete, starting from August 2014 – August 2015.

Location of Race (city, state)	Date Completed	Distance (miles or kilometers. Please indicate unit)	Finishing Time

1. What geographic location do you typically train in? *(select one)*

Within the United States:

New England: Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut

Mid-Atlantic: New York, Pennsylvania, New Jersey

East North Central: Wisconsin, Michigan, Illinois, Indiana, Ohio

West North Central: Missouri, North Dakota, South Dakota, Nebraska, Kansas, Minnesota, Iowa

South Atlantic: Delaware, Maryland, District of Columbia, Virginia, West Virginia, North Carolina, South Carolina, Georgia, Florida

East South Central: Kentucky, Tennessee, Mississippi, Alabama

West South Central: Oklahoma, Texas, Arkansas, Louisiana

Mountain: Idaho, Montana, Wyoming, Nevada, Utah, Colorado, Arizona, New Mexico

Pacific: Alaska, Washington, Oregon, California, Hawaii

Or if outside the United States:

Country: _____ State/Province/Territory/City_____

2. Do you plan to taper for this race? (i.e., diminish or reduce the exercise load during the few days before the race)

   If yes, how many days? _____days

3. What is your predicted finish time?_____minutes
4. What is your strategy for successfully completing this year's race? *(select one)*
      a. I plan on using speed (pace) to guide my running strategy
      b. I plan on using intensity (heart rate) to guide my running strategy
      c. I do not have a plan on using either speed or intensity to guide my running strategy
5. How do you plan to regulate your speed (pace) through ought the duration of the race? *(select one)*
      a. I plan to keep my speed (even pace) the same throughout the race
      b. I plan on starting off the race at a slower speed (negative pace) and increasing my speed throughout the race
      c. I plan on starting off the race at a higher speed (positive pace) and then progressively decrease my speed throughout the race
6. How do you plan to regulate your intensity (heart rate) throughout the race? *(select one)*
      a. I plan on keeping my intensity (heart rate) consistent throughout the whole race
      b. I plan on running at a certain percentage of my heart rate maximum
      c. I will not rely on heart rate to run the race; rather I will focus on my speed (pace)
7. Given your race goes according to your plan, during the last mile of the race, my plan is to: *(select one)*
      a. Increase my speed to meet a goal time
      b. Keep the same speed to be able to finish the race
      c. Maintain the same intensity (heart rate) to be able to finish the race
      d. Change my speed or intensity depending on how I feel
8. What is the make and model of your heart rate monitor device?
9. What are your average hours of training per week?
10. Do you pace yourself by heart rate and/or speed? *(select one)*
         Yes: heart rate
         Yes: speed
         No
      If yes, please provide the goal value (heart rate or speed) of your pace:
11. What are your average hours of training per week? _____-
_____hours/ week
12. Of your average training hours per week, what percentage of them are comprised of:
      a. Running_____%

            i. What percentage of running is done:

                  Inside _____% vs. Outside _____%

      b. Strength Training_____% (any weight resistance exercise)

      c. Cross Training (Elliptical, Bike, Pool, etc.) _____%

11. Please place an X next to the time of day that you normally exercise.

   ____**Early Morning** (4-7am)   ____**Early Afternoon** (1-3pm)

   ____**Mid-morning** (7-9am)   ____**Mid-afternoon** (3-5pm)

____**Late Morning** (9-11)   ____**Evening** (5-8pm)

____**Noon** (11-1pm)   ____**Night** (>8pm)

12. Please describe any type of heat/ sun exposure you have or may have during your training for Falmouth. Please give a range of the amount of time exposed to the sun/ heat. (i.e., work requires outside labor, vacations, recreational activities, etc.)

_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____

13. What is your level of activity? *(select one)*:
    □ Sedentary (no exercise)

    □ Moderately active (occasional exercise)

    □ Vigorously active (heavy exercise)

14. If you have any other concerns regarding your training or preparation, please describe below.

_____
_____
_____
_____
_____
_____
_____
_____
_____
_____

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