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# Physiological, Behavioral, and Knowledge Assessment of Runners' Readiness to Perform in the Heat

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Physiological, Behavioral, and Knowledge Assessment of Runners' Readiness to Perform in the Heat

Yuri Hosokawa, PhD

University of Connecticut, 2016

Many intrinsic and extrinsic factors may contribute to exertional heat stroke (EHS) susceptibility. Despite many plausible risk factors for EHS in runners, much remains unknown about how risk factors contribute to EHS risk and how education to modify behavior may reduce EHS risk. Therefore, this study investigated: (1) the differences between runners' planned and actual hours of sleep, hydration strategies, and intake of medication and supplements at the 2016 Falmouth Road Race (FRR) and their current knowledge on heat safety and hydration, (2) effectiveness of educational video intervention in improving runner's knowledge on heat safety and hydration, (3) effectiveness in detecting internal body temperature and heart rate responses observed during an outdoor road race from a laboratory based modified heat tolerance test (mHTT), and (4) prevalence of EHS risk factors among runners who completed the FRR. Survey results revealed that 90.5% of respondents trained for the FRR and demonstrated 64.3% in their pre race knowledge test [KT] on heat safety and hydration. The educational video resulted in a 15% improvement in KT score, however, effectiveness of the educational video in optimizing runner's behavior is inconclusive. A mHTT was able to track markers of thermal strain independent from anthropometric variables of tested subjects in a controlled-laboratory setting. However, there was a lack of association between laboratory and field observations of internal body temperature and heart rate response. Nonetheless, the current protocol provided future direction in creating a laboratory heat tolerance test that assess runner's ability to exercise in the heat. Lastly, observations of EHS risk factors at FRR were not unique to those who were admitted to the medial tent but were also observed in runners who experienced exercise-induced hyperthermia and runners who did not warrant medical attention at the race. While I found that reported number of risk factors per runner was highest in EHS, more EHS cases are needed to determine if a greater number of risk factors is a unique characteristic among EHS runners. In conclusion, runners exhibited various intrinsic and extrinsic EHS risk factors but presence of these

factors did not demonstrate high specificity or sensitivity in identifying EHS runners.

Physiological, Behavioral, and Knowledge Assessment of Runners' Readiness to Perform in the Heat

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B.A., Waseda University, 2011

M.A.T., University of Arkansas, 2013

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APPROVAL PAGE

Doctor of Philosophy Dissertation

Physiological, Behavioral, and Knowledge Assessment of Runners' Readiness to Perform in the Heat

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TABLE OF CONTENTS

# REVIEW OF THE LITERATURE

Sustained exercise demands blood flow to maintain steady state in cardiac output balanced with thermoregulatory regulation that prioritizes redistribution of the blood to the periphery.[1–3] Cardiovascular and thermoregulatory demands are further amplified when exercise takes place in a thermal environment. Furthermore, the extent to which an exercising individual is affected by the heat depends on various intrinsic and extrinsic factors that may be modifiable or non-modifiable.[4–7] This individualistic difference becomes evident in summer road races, where runners of varying age, training background, health condition, and level of competition participate in the same event.[8–11] Exertional heat stroke (EHS) is a medical condition of a particular concern in summer road races since it can manifest into a lethal condition if not rapidly recognized and appropriately treated within the first thirty minutes of collapse. Laboratory studies using exercise protocols in the heat[1,12–19] and field studies of exertional heat illness (EHI) patients[20–23] suggest that there are disadvantageous phenotypes in maintaining cardiovascular and thermoregulatory homeostasis in the heat, which may predispose runners to experience EHI. Therefore, the primary purpose of this review is to provide an overview of cardiovascular and thermoregulatory response observed during exercise under thermal stress. Additionally, the review will present EHS risk factors that are unique to road race settings and runners.

## Exercise in Heat

### *Cardiovascular and Thermoregulatory Control*

After the initial 5 to 10 minutes of exercise, one's heart rate will increase to maintain cardiac output by offsetting the reduction in stroke volume and arterial blood pressure induced by the redistribution of blood to the skeletal muscles.[1,2] This phenomena is called cardiovascular drift, and allows the body to maintain the arterial pressure during exercise. This mechanism is further challenged under thermal stress due to the additional need to redistribute the blood to the periphery in order to dissipate metabolic heat produced from the exercising skeletal muscles by convective heat loss.[3] Sweat

response induced from elevated skin and internal body temperature will also result in graded dehydration, if plasma volume loss from sweat is not corrected.[24] Consequently, dehydration directly influences the cardiovascular control by increasing the heart rate by 3-4 beats per minute for every 1% body mass loss during exericse.[25] Moreover, for every 1% body mass loss, rectal temperature increases by 0.22°C during exercise in the heat.[26]

In order to prevent a dramatic fluid shift in the body during exercise in the heat, osmoreceptors at the preoptic area of hypothalamus will inhibit the sweating mechanism by adjusting the temperature threshold for sweat secretion upwards upon sensing the increased osmolality in serum.[27–29] By setting the new threshold for sweat onset, the body prevents further plasma volume reduction from sweat. The body temperature threshold for cutaneous vasodilation is also shifted upwards to prevent the cutaneous vasodilation from decreasing the mean arterial pressure, allowing the body to supply blood to the vital organs first.[30] Although sweat secretion is a vital mechanism for human thermoregulation, the priority is to correct body fluid osmolality and to conserve mean arterial pressure during exercise induced hyperosmotic hypovolemia. With the primary mechanism for heat dissipation compromised, the amount of body heat storage becomes the limiting factor for exercise continuation.[27]

*Heat Balance*

The body temperature is determined by the extent of heat storage (S), which is influenced by the metabolic heat production (M), external work performed by the individual (W), evaporative heat exchange (E), radiative heat exchange (R), convective heat exchange (C), and conductive heat exchange (K): $S = M\ (\pm W) - E \pm R \pm C \pm K$. During exercise, approximately 80% of the heat produced by the skeletal muscles turn to heat, which is a major contributing factor of heat gain.[31] The amount of heat generated is proportional to the amount of external work completed by the individual. The difference between the sum of heat gained and heat lost will determine the body temperature.[32] Without the mechanism to dissipate heat efficiently, the internal body temperature may increase by 1°C every 5 minutes in average-sized individual during exercise (metabolic heat production ≈1100W).[33]

Evaporative heat exchange will act to dissipate heat, whereas the heat exchanges through radiation, convection, and conduction could result in heat loss or gain depending on the surrounding environment. The body uses dry-heat loss and wet-heat loss to dissipate excess heat to maintain thermoregulatory balance. Dry-heat loss includes convective and conductive heat loss mechanisms, which relies on the transfer of heat from warm to cool object. For example, cutaneous blood vessels will dilate during exercise to increase the skin blood flow in an attempt to bring the warm blood from the core to the periphery to dissipate the heat through convection. Wet-heat loss is the more effective method of heat dissipation during exercise, accounting for the majority of heat dissipation to offset the heat gain. The increase in body temperature from exercise will induce sweat glands to secrete sweat, which will wet the skin and dissipate heat as it evaporates from the skin. As long as euhydration is maintained and the water vapor pressure in the air is not saturated, wet heat loss provides the most efficient measure of heat loss during strenuous exercise.[33–36] The state in which the heat balance is maintained and the body temperature exhibits a stable plateau is called compensable heat stress.

*Uncompensable Heat Stress*

Uncompensable heat stress is observed when the body cannot maintain a stable plateau in body heat balance due to the inability to dissipate heat at the rate of heat production and often coincides with cardiovascular insufficiency. This imbalance can be caused by extrinsic (e.g., environmental condition, clothing, equipment) and intrinsic (e.g., heat acclimatization status, anthropometric characteristics, hydration status) factors of the exercising individual (Figure 1).[4,5]

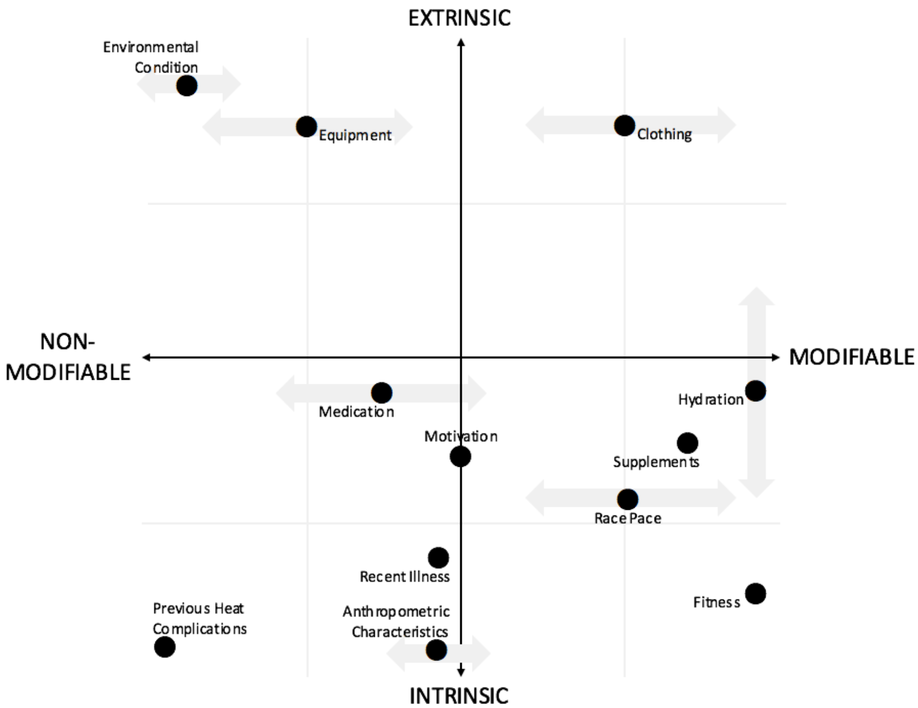


**Figure 1**. Cartesian coordinate graph displaying factors that influence body heat balance when exercising in the heat. Horizontal axis weighs whether the factor is modifiable (+) or non-modifiable (-). Vertical axis weighs whether the factor is influenced by extrinsic variable (+) or intrinsic variable (-) of the exercising individual. Gray band indicates the flexibility of the factor (i.e., hydration can be optimized by the exercising individual [intrinsic factor] but the ability to do so may be limited if water source is not provided or available [extrinsic factor]). ©2016 Hosokawa.

a. Extrinsic factors

The ability for the body to transfer heat relies on the temperature gradient from the core to the skin, and the skin to the environment.[31] Furthermore, evaporative heat loss capacity is highly dependent on the water vapor pressure.[5] Consequently, the environmental condition plays a significant role in determining the maximum efficiency for a person to dissipate heat during exercise naturally.[34,35,37] For example, when hot-dry and hot-wet conditions are compared, a hot-dry environment will have lower ambient vapor pressure, allowing for greater evaporative heat loss. Conversely, when the evaporative heat loss is hindered, the rate of heat production or gain will increase exponentially.[37] Moreover, when the ambient temperature is greater than the skin temperature, the temperature gradient between the air and

skin will favor convective heat gain. This convective heat gain occurs when the ambient temperature exceeds approximately 35°C.[34]

Microclimate created between the skin and clothing or equipment also limits the body from dissipating heat due the lack of airflow and restriction of evaporative heat loss.[34,38,39] Under a fixed low intensity exercise, increased skin coverage induced a faster rate of rise in esophageal temperature.[38] Consequently, when a reduction in the zone of compensable heat stress is observed, the athletes may be more vulnerable to EHI.[38] Similarly, when exercise time and rectal temperature were compared across minimal athletic clothing, partial American football uniform, and full American football uniform, full American football uniform trials resulted in the least number of participants completing the full exercise trial due to volitional exhaustion and exhibited the highest rate of rise in rectal temperature.[39]

b. Intrinsic factors

Relative aerobic capacity of a person (i.e., $VO_2max$ expressed in $ml \cdot kg^{-1} \cdot min^{-1}$) may influence the degree of exercise intensity one can tolerate in the heat,[4,12,40] due to the greater cardiovascular demand that is placed to the exercising individual when completing a fixed work intensity in a hotter environment.[13] Therefore, a greater $VO_2max$ may indicate a wider working range of cardiovascular stability.[4,40,41] However, studies suggest that $VO_2max$ may not independently influence one's ability to thermoregulate while exercising in the heat per se,[14,42] as physiological adaptations observed from heat acclimatization such as increased plasma volume, earlier onset of sweating, increased skin blood flow, attenuation in rate of rise of heart rate and internal body temperature are the direct changes that influence thermoregulatory capacity.[4,15,33,43,44]

This relationship between $VO_2max$ and one's exercise capacity in the heat should be considered carefully because the ability to sustain strenuous exercise in heat among runners with high aerobic capacity will innately result in greater metabolic heat production due to greater external work completed.[16] Not surprisingly, runners with low aerobic capacity will likely to be producing lesser metabolic heat since the upper threshold for exercise intensity is lowered. However, this also implies that

less fit runners may be exercising in a narrow window of cardiovascular and thermoregulatory capacity.[15] As a result, the relative metabolic heat strain experienced in runners with low aerobic fitness may be greater than those who are aerobically fit despite producing less metabolic heat. This issue also becomes apparent when unfit individuals are forced to exercise at an intensity unmatched to their physical fitness and are not provided with self-regulated rest breaks.[20]

Anthropometric characteristics of the runner like body mass, body surface area, and body fat, will also influence one's capacity to thermoregulate during exercise.[5,14,17,42] At a fixed work load, body morphology determines the rate of heat gain and dissipation. For example, individuals with greater body mass will store more heat (i.e., faster increase in rectal temperature) when they are working at fixed rates of metabolic heat production than those with less body mass.[17] This relationship also holds true when two individuals with different body mass, but the same aerobic fitness are compared.[45] In this scenario, the individual with greater body mass will experience greater heat storage despite the similar fitness level. When the workload is corrected to their body mass (i.e., bike ergometer at $5W \cdot kg^{-1}$), the difference in the rate of heat gain is diminished, implying that the amount of heat storage is directly influenced by the combination of exercise intensity (i.e., external work load) and body mass.[32] Body surface area is a critical factor that determines the heat dissipation capacity.[5,34] Greater body surface area to mass ratio (BSA/M) is favored in dry heat conditions since it allows the body to maximize the contact of skin with the environment to transfer heat through convection and conduction. Furthermore, when air vapor is saturated, individuals with greater BSA/M may be at a advantage.[5] For example, under hot-wet conditions, Shapiro et al.[46] observed better heat tolerance in female participants than male participants. This is due to the larger body surface area to body mass ratio observed in female participants who may be more efficient in losing heat via convection when evaporative heat loss is limited due to the high relative humidity.[46] On the contrary, when the environmental temperature exceeds the skin temperature, large BSA/M will introduce greater heat gain, which will not work in favor during prolonged exercise. Although sex and age has been argued to alter the heat tolerance capacity, the direct influences from these

factors are difficult to quantify. The common morphological and physiological differences associated with sex and age are likely to explain mechanisms as to why these populations have reduced ability to exercise in the heat.[47]

Hydration status also has a significant influence in shifting the heat balance by compromising the sweat production and contributing to increased internal body temperature.[26–29] Continued loss of plasma volume due to sweat production will also result in rises in heart rate and internal body temperature, further disrupting the cardiovascular stability while exercising in the heat.[24,48,49]

### *Assessment of Heat Tolerance*

Numerous testing methods have been proposed to assess exercise heat tolerance (Table 1).[31,50–55] These methods require measurement of physiological responses during a bout of exercise in varying intensity under thermal strain. Testing methods can be classified into two groups: the first group of tests is based on the change in physiological response observed during and/or after exercise trial[50–55], while the second group of tests is based on the principles of the heat balance equation in which the rate of metabolic heat production and dissipation are measured using calorimetry or estimated thermometry models to examine body heat storage.[5,31] The use of a physiological response based test is more practical compared to the calorimetry/estimated thermometry method. The Israeli Defense Force (IDF) heat tolerance test is one of the most commonly used protocol in physically active population and post EHS patients in assessing their readiness to conduct physical activity in the heat.[12,50,53,56–59] However, the external validity of the IDF protocol in females and athletes is controversial.[52,58]

## **Road Race Medicine and Heat**

### *Injury Epidemiology*

Medical management in road race setting has its own challenges that are considerably unique from other organized sports. First, road race events may host runners of varying age and physical ability.[60–62] This requires extra considerations from the race organizers to address the needs from runners

who may complete the race in various times. Furthermore, physical preparation and readiness to participate in a race is contingent on registrant, and race organizers are limited in making the registration decision since entry to these races is voluntary. For example, Two Oceans Ultra-Marathon (Cape Town, South Africa) observed in their four-year medical record data, the greatest overall incidence rate of medical complications (e.g., postural hypotension, exercise associated muscle cramp, gastrointestinal complication, musculoskeletal complications, dermatological complications) was in individuals who were categorized to have the least experience of running (least experienced, 16.44 per 1,000 runners, 95%CI[13.82, 19.57]; somewhat experienced, 10.62 per 1,000 runners, 95%CI[8.59, 13.12]; most experienced, 12.14 per 1,000 runners, 95%CI[10.12, 14.57]).[63] Large scale events could also host tens of thousands of runners, and the scene of on-site medical care can quickly become chaotic if not planned properly. Furthermore, each race is unique in the terrain, course set-up, time of the year, and environmental condition.[64–73] As a result organizations have developed guidelines and recommendations to help manage the situation in a structured manner.[74–77]

Numerous road races have published medical tent admittance data to elucidate incidence of commonly observed medical conditions in runners on the day of competition.[62,63,68,78,79] The majority of medical conditions seen at road race medical tents are self-resolving after rest and oral fluids and requires brief stays in the medical tent.[10,62,72] However, there are conditions such as cardiac arrest, exertional hyponatremia, EHI, and exercise associated collapse that necessitate on-site medical care.[72,74] These injuries may warrant intravenous fluid administration, medication, prolonged observation, active heating or cooling, or hospital referral.[8,74,79] Moreover, the number and type of medical tent admittance could vary significantly at the same event depending on the race day climate condition.[62,63,67,77] Epidemiological data suggest that extreme weather (i.e., hot and cold) and high humidity increase overall number of medical admittance.[63,67,78] Therefore, global precautions to address foreseeable medical complication is warranted, especially when dealing with a sizeable number of runners with unknown risk profile.

Heat related illnesses are of particular concern to race medical staff because they could affect runners of all ages and training status at races of varying distances.[64–73,80] Elite, fast runners are likely to have a physiological advantage and ability to sustain exercise under thermal stress; however, risk of overriding the body's thermoregulatory capacity exists when exercise is sustained at a high intensity that produces significant amount of metabolic heat.[33] On the contrary, less fit, slow runners may be exposed to thermal stress for a prolonged period of time, leading to significant heat gain from solar radiation.[81]

*Heat illness Risk Factors Unique to Road Races*

a. Extrinsic factors

A clear relationship between the climate conditions and incidents of EHS and EHI was observed from 18 years of climate and medical tent admittance data from the Falmouth Road Race (Falmouth, MA, USA).[67] Average ambient temperature ($T_A$) and Heat Index (HI) during the race demonstrated strong association with the incidence rate of EHS ($T_{A,}$ $R^2$=0.65; HI, $R^2$=0.74) and EHI ($T_{A,}$ $R^2$=0.71; HI, $R^2$=0.76), indicating that heat gain from the environment amplifies the thermal strain experienced by runners.[67] Similarly, full marathon finish times recorded in Boston, Chicago, London, New York, and Paris from 2001 to 2010 showed that higher $T_A$ in the first hour of the race adversely influenced runners' performance and increased the number of race withdrawals regardless of competition level.[82] Data also suggest that increased $T_A$ influences slower runners more than the faster runners independent of sex .[83,84] Environmental conditions are not the only factor that impact EHI/EHS risk. Epidemiological studies suggest that EHI and EHS is more prevalent in shorter distance race (≈10km) than half, full, and endurance marathons.[62,64,66,67] The probable reason for greater number of EHI and EHS in shorter distance races is the increased likelihood of runners sustaining faster-paced running for the entire duration of the race that results in a greater metabolic heat production, while runners will likely to choose a slower pace in longer distance races in order to sustain their activity for longer duration.[67]

b. Intrinsic factors

The nondiscriminatory nature of race registration invites runners of varied running experience, physical fitness, heat acclimatization, and medical history to participate in the same event, all of which have been shown to influence an individual's predisposition to EHI and EHS. Previous studies have identified that inexperienced individuals, participation in physical activity unmatched to the physical fitness, and large body mass are common characteristic of EHI and EHS victims.[20,22,23] However, there is a lack of observational studies to investigate specific intrinsic factors that may increase the runner's risk of suffering EHI in road races.

Aging may decrease a runner's aerobic capacity over time, however, aging does not negatively impact marathon and half-marathon performance independent from the physiological change per se.[60] Untrained or less trained runners are likely to experience greater thermal strain compared to experienced runners regardless of age.[85] Previous heat exposure and heat acclimatization status will also influence one's ability to sustain exercise in the heat.[15] Through heat exposure during exercise, one may gain increased cardiovascular stability (i.e., decreased heart rate, plasma volume expansion) and enhanced thermoregulation (i.e., increased sweat rate, earlier onset of sweat secretion, decreased sweat sodium concentration).[18,43,86] In the absence of these adaptations, runners may experience uncompensable heat stress earlier in a race due to the inability to efficiently lose body heat. Of the thirty-one runners studied in the 2015 Falmouth Road Race, median total exercise time at or above the race day HI during the four-week period before the race was only 4 hours and 22 minutes, ranging from as short as 11 minutes up to sixteen hours.[11] This demonstrates that many runners at the Falmouth Road Race are not incorporating heat exposures to their training regimen. Lack of previous heat exposure was also shown to increase the likelihood of experiencing heat exhaustion among runners in a 14-km road race and full marathon.[64,65] However, the number of training sessions required to build heat tolerance has not been fully elucidated.[87,88]

Internal motivation can also influence runner's pacing strategy.[19,64] Faster race pace is positively correlated with the increased heat production and higher rectal temperature.[89,90] End spurt is a commonly

observed behavior in competitive settings during which the runner increases the pace in the last segment of the race. This may also drive the heat production upwards if a runner is already exercising at near-maximal exertion and may shift the heat balance from compensable heat stress to uncompensable heat stress. In a case control survey study conducted at the Sun-Herald City to Surf Fun Run (Sydney, Australia), runners who reported traits that demonstrate high motivation had greater risk of experiencing heat exhaustion.[64] When the race pace is not self-controlled, it may also predispose the runner to uncompensable heat stress due to the inability to reduce the work rate accordingly to the anticipated heat stress.[91]

Dehydration is one of the most commonly observed symptom of EHI.[7,75] In the Sun-Herald City to Surf run, runners who did not hydrate before the race had two fold increase in the risk of heat exhaustion. Furthermore, lack of fluid intake during race resulted in ~5 fold increase in the risk of heat exhaustion.[64]

Recent illness and associated use of medication may also influence runner's predisposition to heat related illnesses.[20,92,93] Runners may be taking medications that may negatively influence thermoregulation during exercising in the heat.[92] For example, antihistamine and anticholinergic drugs reduce sweat production. Calcium channel blockers and female reproductive hormone replacements reduce skin blood flow and amphetamines increase heat production and elevate the hypothalamic set point.[92] Aspirin is also a popular medication used by runners to manage muscle pain and also used as a prophylactic medication to prevent myocardial infarction.[94] Aspirin has been associated with increased gastrointestinal permeability post-exercise[95], which may amplify the clinical manifestation of gastrointestinal distress commonly observed in EHI and EHS runners.[96,97] A similar observation was made by Smetanka et al.[98] in runners who ingested ibuprofen before Chicago Marathon (Chicago, IL, USA). Increased gastrointestinal permeability has been linked to endotoxemia, which may explain part of the systemic inflammatory response observed in EHS.[97,99] A pre-race acute illness questionnaire administered by Van Tonder et al. also revealed that 19% of the runners who participated in the survey

experienced sore throat, runny nose, general tiredness, blocked nose, headache, and muscle pain eight to twelve days prior to the race day.[93] Since some of the symptoms may warrant the use of aforementioned drugs, education is needed to provide runners with an opportunity to make a well-informed decision about postponing or cancelling their race pariticpation.[93]

c. Organizational factors

Organizational factors such as race distance, start time, time of the year, and number of hydration stations available on course are extrinsic risk factors that could substantially influence the risk of EHS and EHI.[74] These factors are non-modifiable to the runners but can be adjusted by race organizers, if planned accordingly. The potential impact of severe weather on the number of EHI patients should not be underestimated[66,67,77], and implementation of policies to adjust or cancel a race is also an organizational factor that may shift the risk considerably. For example, 2012 Boston Marathon (Boston, MA, USA) offered a deferment for runners to participate in the subsequent year due to the unseasonably hot weather forecast reaching mid-80's.[100] Similarly, 2016 Vermont City Marathon (Burlington, VA, USA) cancelled the race at noon when WBGT readings from all monitoring stations along the course exceeded 82°F.[101]

**Assessment of Runners' Behavior and Knowledge**

Road race medical staff do not have access to registrants' health information prior to the race, largely due to the limitation in obtaining such information when the participation is open to everyone. Instead, clinicians and researchers have developed surveys to investigate characteristics that may predispose runners to warrant medical attention on race day.[9,65,66,93] Although these survey data are not currently used to screen participants, they still provide valuable information in understanding the mosaic of runners who are registered to partake in the event. Van Tonder et al.[93] examined the prevalence of recent illness among runners who were registered in the Sun-Herald City to Surf run. The survey result revealed that 530 out of 7,031 runners who reported of having recent acute illness before the race day still participated in the race, and had two times higher risk of not completing the race compared to the healthy cohort.[93] Satterthwaite et al.[9] found a similar finding from their survey at the Auckland Marathon

(Auckland, New Zealand) that runners who reported of having recent illness experienced greater odds of constitutional health problems (e.g., light-headedness, nausea, diarrhea, gastrointestinal distress, chills) during or after the race.

O'Neal et al.[102] conducted a pre-race survey focusing on hydration practices and perceptions in runners participating in Little Rock Half Marathon and Marathon (Little Rock, AR, USA). The investigation observed high perceived importance in staying hydrated during the race, however only 20% of the survey respondents had specific measures to monitor their hydration status.[102] Furthermore, a runner's own experience and stories from other runners had greater influence on runner's preference in hydration behaviors than peer reviewed research articles.[102] Lack of understanding in individualized fluid-intake was also observed.[102] Their survey results may have been influenced by the sampled population since the survey respondents were non-elite, recreational runners who do not have regular supervision by health care professionals during their training. Nonetheless, the survey was able to identify the lack of knowledge regarding hydration strategies and also the lack of knowledge transfer to modify hydration practice. Similarly, Kretsch et al.[65] conducted pre and post surveys among non-elite runners in the Melbourne Big M Marathon (Melbourne, Australia), which revealed only 4% of the survey respondents had adequate fluid intake before the race.[65] Furthermore, 33% of the survey respondent self-reported having pre-existing health problems going into the race, including musculoskeletal injuries and gastrointestinal illness. These runners also had 60% less chance of finishing the race.[65]

**Heat Related Illness Risk Mitigation and Prevention**

American College of Sports Medicine and International Institute of Race Medicine have published guidelines and recommendations, primarily targeting the race organizers and medical staff to mitigate EHI risk.[74,76] Modification or cancellation of a road race according to the WBGT and equipping the medical tent with appropriate tools for EHS recognition and treatment (e.g., rectal thermometer, ice, water, immersion tub, towels) are two key methods that have shown direct impact in reducing the EHI morbidity and mortality.[67,68] However, little has been done to educate runners on modifiable EHI risk

factors with a goal to optimize their behaviors while preparing for warm weather races (i.e., hydration strategy, heat acclimatization, implication of recent illness and poor physical fitness). Education about intrinsic and extrinsic factors of EHI to build awareness among runners is a vital constituent for successful EHI prevention program in road race events. Nevertheless, structured educational intervention regarding the risk factors for EHI in runners are currently lacking.

Although retrospective investigation on injury rates and characteristics of the patient population is economical, more prospective studies needs to be conducted to understand the risk factors, especially when the mechanism of the injury is well-defined. In the context of EHI research, intrinsic and extrinsic factors are well-established from laboratory based studies and observational field studies.[4,7,19,20,64,66] Moreover, good understanding of the underlining physiology (i.e., cardiovascular and thermoregulatory control), physics (i.e., interaction with thermal environment), and behaviors surrounding the exercising individual needs to be considered collectively to explain the complexity of EHS risk factors (Figure 2). Further investigation to identify the magnitude of influence these established factors have on EHI vulnerability can not only help tailor the educational material to prevent EHI but may also help establish a screening tool to assess one's readiness to safely exercise in heat.

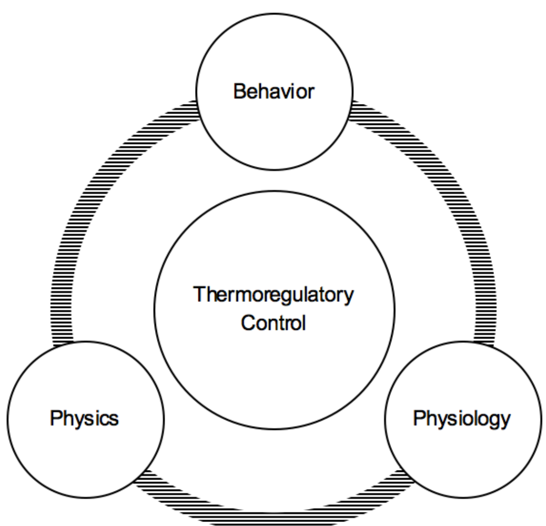


**Figure 2.** *Factors influencing thermoregulatory control.*

**Table 1. Methods to Evaluate Heat Tolerance**

| Author | Background | Protocol | Required Variables | Indications of Heat Intolerance | Application |
|---|---|---|---|---|---|
| Kenney et al. (1986) | Aimed to predict the point of physiological limit when conducting a continuous workload of 275kcal·hr$^{-1}$ under thermal condition (WBGT, 40°C) | • Neutral $T_A$ ≈23°C<br>• Workload ≈600kcal·hr$^{-1}$<br>• 20 minutes | • HR | • NA; work duration is adjusted accordingly to the HR measured 5 minutes post exercise protocol (see Kenney et al. Table III) | Laborer |
| Dennis and Noakes (1989) | Aimed to examine the maximal speed in which runners with different body size can maintain their thermal balance under different configurations of $T_A$ and RH | • NA; maximal speed is calculated from estimated heat production, heat exchange via conduction, heat transfer via radiation, and heat loss by evaporation | • Body mass<br>• Body surface area<br>• Running speed<br>• $T_A$<br>• RH | • NA; maximal tolerable speed while maintaining thermal balance is calculated by the maximal heat loss capacity allowed | Endurance runner |
| Epstein (2012) Druyan et al. (2013) | Aimed to examine the cardiovascular and thermoregulatory stability | • Climatic chamber set at $T_A$ 40°C and RH 40%<br>• Treadmill walk 5km·h$^{-1}$ at 2% grade<br>• 120 minutes | • $T_{REC}$<br>• HR | • $T_{REC}$ >38.5°C<br>• HR >150b·min$^{-1}$<br>• $T_{REC}$ and/or HR not reaching a plateau (e.g., rate of rise in the second hour >0.45°C·min$^{-1}$ | Israeli Defense Force |
| Jay and Kenny (2007) | Aimed to develop a thermometry model that is able to detect the change in body heat content during exercise | • Does not choose exercise context | • Body mass<br>• $T_{REC}$<br>• $T_{SKN}$ | • NA; change in body heat content indicates the magnitude of thermal strain | Nonspecific |

| | | | | | |
|---|---|---|---|---|---|
| Johnson et al. (2013) | Aimed to profile exercise heat response at various time points in a high-level athletes to identify key criteria that corresponds with improved exercise heat tolerance | • Climatic chamber set at $T_A$ 36°C and RH 50%<br>• Cycling at 70% of $VO_2$max<br>• 90 minutes<br>• Pre and post tests required for comparison | • $T_{GI}$<br>• HR<br>• Sweat rate<br>• Exercise duration | • Increased exercise duration until reaching $T_{GI}$>39.5°C<br>• Reduction in $T_{GI}$<br>• Reduction in HR<br>• Increase in sweat rate | Triathlete |
| Mee et al. (2015) | Aimed to examine exercise heat tolerance in endurance runners by using exercise intensity that mimics running | • Climatic chamber set at $T_A$ 40°C and RH 40%<br>• Treadmill run 9km·h$^{-1}$ at 2% grade<br>• 30 minutes | • Peak $T_{REC}$<br>• Peak $T_{SKN}$<br>• Peak HR<br>• Peak PSI<br>• Sweat rate | • NA; further study is warranted to identify a clinical threshold that indicates heat tolerance | Endurance runner |
| Roberts et al. (2016) | Aimed to evaluate physiological response under realistic exercise intensity in the heat | • Climatic chamber set at $T_A$ 25°C and RH 60%<br>• Treadmill run 10.5-12.9km·h$^{-1}$<br>• 70 minutes | • Perceived exertion<br>• Perceived thermal strain<br>• $T_{REC}$<br>• HR | • NA; test results should not be used alone, however, clinicians are encouraged to use the information to guide clinical diagnosis | Endurance runner |

Abbreviations: HR, heart rate; NA, not applicable; RH, relative humidity; $T_A$, ambient temperature; $T_{GI}$, gastrointestinal temperature; $T_{REC}$, rectal temperature; $T_{SKN}$, skin temperature; $VO_2$max, maximal oxygen consumption; WBGT, wet bulb globe temperature.

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## CHAPTER I. RUNNER'S RACE DAY BEHAVIORS AND KNOWLEDGE ON HEAT SAFETY AND HYDRATION

### INTRODUCTION

On-site medical care in road race events is uniquely challenging. Road races attract runners with a wide range of training backgrounds, age, and health status, and runners participate in races at their own discretion with no medical screening requirements. In 2015, International Road Race Medicine published guidelines that address evidence based practice to manage various medical conditions that are commonly seen in road race events.[1] In the document, participant education is highlighted as being critical to the reduction of medical attention at races.[1] Educational tools have been utilized in different sport settings, containing materials related to common medical conditions in the sport and safety considerations for particiapnts.[2] However, there are no standardized education modules for recreational runners.

Exertional heat stroke (EHS) is among the top health concerns of medical tent admittance at road race events, especially when it takes place in warm weather.[3–9] Falmouth Road Race (Falmouth, MA) reported the largest dataset (n=393) of EHS and heat exhaustion cases treated at their medical tents from eighteen years of medical records. [3] Although no fatalities were reported at the Falmouth Road Race owing to the immediate diagnosis and rapid cooling to treat runners on site,[10] further effort is warranted to reduce the incidence of exertional heat illness (EHI) to decrease the number of medical tent admittance.

EHI risk may be heightened at the Falmouth Road Race due to the warm weather commonly experienced when the race takes place (mid-August). Moreover, additional risk factors may exist that are modifiable, which runners should be educated to correct.[11–18] For example, lack of heat acclimatization and physical fitness are associated with greater risk of EHI.[11–14,18] Exercise intensity unmatched to one's physical fitness may also induce physical strain that is beyond one's capacity to maintain thermoregulatory and cardiovascular stability.[15,18] Therefore, it is vital for the runners to have adequate training and recognition of their physical capacity when exercising in heat. Recent illness is also reported

as a risk factor for EHS[15] and increases the likelihood of a runner not completing a race.[17,19] Use of certain medications is also reported to have association with exertional heat illness and gastrointestinal distress, suggesting that runners who are ill enough to be taking medication should consider postponing event participation.[16,17,19,20] Furthermore, lack of adequate fluid intake is associated with EHI and other medical complications in physical activities.[15,19,21] Therefore, knowledge of modifiable risk factors might impact runners behavior and reduce risk of injury in road race runners.

Thus, the aim of the study was two-fold: first to investigate race registrants' demographics and behaviors surrounding the 2016 Falmouth Road Race, and secondly, to investigate the effectiveness of heat safety and hydration video education. It was hypothesized that the video education will improve runners' knowledge on heat safety and hydration and reduce behaviors that are associated with increased risk of EHI on race day.

## METHODS

### *Survey*

The KT (knowledge test) and educational video contents were developed by the primary investigator and reviewed by three researchers who were certified athletic trainers with doctoral degrees in Exercise Science and whose expertise were on exertional heat illness. Since this was our first endeavor to test runners' knowledge about heat safety and hydration and to use the educational video to improve their knowledge, no pilot test was conducted preceding the survey instrumentation.

An online survey link to the pre race questionnaire ($PRE_{RACE}$) was sent to the registrants of the 2016 Falmouth Road Race (n=11,355) three days before the race (Qualtrics LLC, Provo, UT). $PRE_{RACE}$ included: ten questions concerning training history and habitual and planned behaviors associated with the race, twenty questions structured to test knowledge about heat safety and hydration considerations while exercising in heat (KT, knowledge test), and six questions about participant characteristics

(Appendix I, Section I, II, III). The KT included fourteen questions about heat (Appendix I, Section II: Q4, Q5, Q6, Q7, Q8, Q9, Q10, Q11, Q12, Q13, Q14, Q17, Q18, Q20) and six questions about hydration (Appendix I, Section II: Q1, Q2, Q3, Q15, Q16, Q19).

Each registrant was randomly assigned to one of the two groups: a group with an additional link to educational video on heat safety and hydration (EDU; n=5678) and a group with no link to the educational video (NED, n=5677). The educational video (duration, 4.7 minutes) contained evidence-based recommendations to optimize running performance in the heat and mitigate exertional heat illness risks through optimal race preparations (Appendix II). Participants who completed $PRE_{RACE}$ in EDU received educational video and a link to complete the KT (Appendix I, Section II) to compare the KT score from $PRE_{RACE}$ to after video education ($POST_{EDU}$). A follow-up email with a link to the post race questionnaire was sent in the afternoon of race day ($POST_{RACE}$). $POST_{RACE}$ included: nine questions concerning race day, the same KT, and six questions on participant characteristics (Appendix I Section III, IV, V). $POST_{RACE}$ was sent to EDU participants that completed $POST_{EDU}$ and NED participants that completed $PRE_{RACE}$ to obtain their recollections on race day behavior (Figure 1.1).

The survey software generated and assigned a random code number that is unique to each participant upon completing the $PRE_{RACE}$. The same code number was carried over by the same participant in the subsequent survey responses (e.g., $POST_{EDU}$, $POST_{RACE}$) to track changes in survey responses across time points. Reminder emails were sent to each group before and after race day to maximize the $PRE_{RACE}$ and $POST_{RACE}$ response rate (RR). Runners were informed that participation to the survey was voluntary.

### *Statistical Analysis*

All statistical analyses were completed using SPSS (version 21; IBM Corporation, Armonk, NY). RR was calculated by the fraction of survey respondents over the total number of runners who received

the survey.  All parametric and nonparametric data are reported in mean±standard deviation (SD) and median±range, respectively. Mean difference (MD) and 95% confidence interval (CI) are reported for group mean comparisons. Chi-square test was used to identify if there is difference in the number of EDU and NED runners who: participated in the race despite feeling sick the day before, took medication or supplements, and knew their sweat rates. A three-way contingency analysis using mosaic plot was used to detect change in runner's intention ($PRE_{RACE}$) and behavior ($POST_{RACE}$) to use a certain hydration strategy (yes, no) by survey group (EDU, NED). Statistical significance was set at $p<0.05$.

## RESULTS

### *Response Rates and Demographics*

The RR at $PRE_{RACE}$, $POST_{EDU}$, and $POST_{RACE}$ are summarized in Figure 1.1. Participants' age, sex, number of Falmouth Road Race completed, and medical training background, if any, are summarized in Tables 1.1-1.5. Most (90.5%) of the survey participants reported they were training for the 2016 Falmouth Road Race. Fifty-three participants (27.0 per 1,000 runners; EDU, n=33; NED, n=20) reported history of heat syncope, heat exhaustion, EHS, classic heat stroke, or rhabdomyolysis (Table 1.6). Sickness during the seven days leading up to the day of the race was reported in 165 (8.4%) survey participants at $PRE_{RACE}$ (total survey respondents, 1,962; 84.1 per 1,000 runners). Furthermore, 472 (24.1%) survey participants reported that they planned on taking medication and/or supplement on race day at $PRE_{RACE}$ (total survey respondents, 1950; 242.1 per 1,000 runners). Detailed list of medications and supplements are summarized in Appendix III.

### *Knowledge on Heat Safety and Hydration*

Mean KT score at $PRE_{RACE}$ was 64.3% with no difference between EDU and NED (MD[95%CI]=0.002 [-0.016, 0.019]; $p$=0.367). For $PRE_{RACE}$, $POST_{EDU}$, $POST_{RACE}$ comparison, data from 592 participants (EDU, n=133; NED, n=459) that completed surveys at all time points were used. The percentage of EDU and NED participants that answered correctly to each knowledge test question and mean KT score at $PRE_{RACE}$, $POST_{EDU}$, and $POST_{RACE}$ are summarized in Figures 1.2-1.5 and Table 1.7. EDU started with a slightly higher $PRE_{RACE}$ KT score than NED (MD[95%CI]= 0.020 [0.002, 0.039]; $p$=0.033). EDU scored considerably greater at $POST_{EDU}$ than $PRE_{RACE}$ (MD[95%CI]= -0.154 [-0.178, -0.130]; $p$<0.001) and no change was observed from $POST_{EDU}$ to $POST_{RACE}$ (MD[95%CI]= 0.026 [-0.0002, 0.051]; $p$=0.052). The KT score was lower, from $PRE_{RACE}$ to $POST_{RACE}$, in NED (MD[95%CI]= 0.013 [-0.0002, 0.025]; $p$=0.053). The test score was considerably greater in EDU than NED at $POST_{RACE}$ (MD[95%CI]= 0.162 [0.142, 0.181]; $p$<0.001). Participants age, sex, and medical training background did not have influence on KT score (age, F[7,1299]= 1.484, $p=0.169$, $R^2$=0.008; sex, F[1,1305]= 2.383, $p=0.123$, $R^2$=0.002; medical training, F[1,1305]= 2.822, $p=0.093$, $R^2$=0.002).

$PRE_{RACE}$ KT on heat safety and hydration (Appendix I, Section II) showed that 89% of survey respondents (EDU, 88%; NED, 90%) did not know that EHS can be life-threatening if not treated properly (KT, Q7). Half of the survey respondents (EDU, 50%; NED, 50%) also did not correctly answer the number of consecutive days of heat exposure that are required for the body to adapt to exercising in the heat (i.e., heat acclimatization) (KT, Q9). Many runners (EDU, 44%; NED, 48%) did not believe that an increase in sweat production was reflective of body's adaptation to exercising in the heat (KT, Q10). Furthermore, approximately half of the respondents (EDU, 43%; NED, 47%) had a misconception that heat exhaustion has a similar cause as fever (KT, Q14). Defining body temperature for EHS was a question that had least number of correct answers at $PRE_{RACE}$ (EDU, 24%; NED, 22%) (KT, Q20). On the contrary, a high percentage of survey respondents were able to recognize that: a runner may be susceptible to heat syncope if the runner is not well hydrated (EDU, 99%; NED, 99%) (KT, Q4); EHS does not only occur when the outdoor temperature is above 90°F (EDU, 98%; NED, 96%) (KT, Q13);

one may drink too much water during exercise (EDU, 91%; NED, 90%) (KT, Q15); and recent illness may predispose a runner to experience heat illness (EDU, 97%; NED, 99%) (KT, Q18).

*Intentions and Observed Behaviors Surrounding Race Day*

The average hours of sleep reported at $PRE_{RACE}$ was greater than the self-reported hours of sleep at $POST_{RACE}$ ($PRE_{RACE}$, 6.91±0.89 hours; $POST_{RACE}$, 6.49±1.17). There was no difference in the hours of sleep reported by EDU and NED at $PRE_{RACE}$ (MD[95%CI]=-0.054 [-0.226, 0.119]; $p$=0.541) and $POST_{RACE}$ (MD[95%CI]=-0.190 [-0.426, 0.036]; $p$=0.099). Sixty-percent of participants in both groups reported that they slept in an air-conditioned room day before the race.

At $POST_{RACE}$, 5.0% of survey participants reported that they were sick the day before the race (total survey respondents, 635; 50.4 per 1,000 runners). There was no difference in number of participants who reported being sick between EDU and NED at $POST_{RACE}$ (EDU, 6.0%; NED, 4.8%; $\chi^2$[1, N=592]=0.320; $p$=0.572). When the number of survey participants who took medication and/or supplement at $PRE_{RACE}$ and $POST_{RACE}$ was compared (n=592), it increased from 22.6% to 34.3% of the runners ($\chi^2$[1, N=1182]=20.090; $p$<0.001). There was no difference in proportion of survey participants who knew their sweat rate at $PRE_{RACE}$ and $POST_{RACE}$ ($PRE_{RACE}$, 9.1%; $POST_{RACE}$, 8.4%; $\chi^2$[1, N=1184]=0.169; $p$=0.681).

Participants selected similar race day hydration strategies at $PRE_{RACE}$ (i.e., intention) and $POST_{RACE}$ (i.e., race day behavior): drink ample amount of water the night before ($PRE_{RACE}$, 93.4%; $POST_{RACE}$, 92.7%), take a drink at water station(s) along the course ($PRE_{RACE}$, 74.5%; $POST_{RACE}$, 77.6%), and avoid alcohol the night before ($PRE_{RACE}$, 75.5%; $POST_{RACE}$, 62.1%) (Figure 1.6). Change in the number of runners' intention and their race day behavior for each hydration strategy is summarized in Figures 1.7-1.14. The number of runners who decided to follow thirst to drink on race day despite their

intention to not use thirst was greater than the expected value in EDU than NED (EDU, Pearson residual [PR]= >2.0; NED, PR=<-4.0) (Figure 1.15).

**DISCUSSION**

The survey was our first endeavor to investigate Falmouth Road Race registrants' demographics and race day behaviors. A wide age range was represented in the survey, which is not surprising at Falmouth Road Race since it does not require a qualifying time at registration. The number of Falmouth Road Races completed before 2016 ranged from 0 to ≥10, with approximately 30% of the survey participants running the Falmouth Road Race for the first time. An assortment of medications and supplements were reported by runners at $PRE_{RACE}$ and $POST_{RACE}$ (Appendix III). Non-steroidal anti-inflammatory drugs were the most commonly used medications by runners. Daily medications used to control diabetes, hypertension, asthma, and dyslipidemia were also common. Several categories of medications that may increase heat production (aspirin, selective serotonin reuptake inhibitor, stimulant), decrease sweat production (anticholinergic, antihistamine), alter skin blood flow (calcium channel blocker, hormonal contraception), and decrease cardiac contractility (beta blocker, calcium channel blocker) were also reported, which may warrant special attention if runners with these medication plan on competing in the race at their maximal effort.[16] In KT, we observed more than a quarter of participants demonstrated a lack of knowledge in: the amount of fluid they should consume to stay hydrated, method of detecting dehydration, risk factors and recognition of heat illnesses, and characteristics of heat acclimatization (Figures 1.2–1.5) (Appendix I, Section II: Q2, Q3, Q5 Q6, Q7, Q9, Q10, Q14, Q20). However, it should be noted that evaluation of runner's knowledge on heat safety and hydration using KT may have been limited by the true-or-false and multiple choice question format, which did not allow participants to elaborate on their answer in an open-ended form.

The video education about heat safety and hydration improved KT score in EDU immediately after viewing the video by 15% (Table 1.7). There was a small, non-significant difference between KT score at $POST_{EDU}$ and $POST_{RACE}$ in EDU participants, suggesting that they were able to retain information from the educational video for one to three days, depending on when they took the survey.

My study also compared runner's intention and actual behavior at the race through prospective ($PRE_{RACE}$) and retrospective ($POST_{RACE}$) surveys and investigated the influence of the educational video in reducing behaviors that are associated with increased risk of EHI. Survey results revealed that illness during the seven days leading up to the race day and the day before the race did not stop some runners from participating in the race despite the high recognition of recent illness as a risk factor of heat illness in KT. A similar finding was found in the surveillance study conducted at the Melbourne Marathon where 11% of the runners who participated in the race answered they experienced infectious disease before the race.[19] The educational video also highlighted that increased sweat rate as one of the primary adaptations observed through heat acclimatization and sweat rate should be calculated to optimize the hydration plan (Appendix II). However, no change was observed in runners' knowledge on sweat rate (KT, Q10; $p$=0.902) and no difference was observed in the number of participants who knew their sweat rates between EDU and NED. Runners' race day hydration strategies reported at $PRE_{RACE}$ and $POST_{RACE}$ were similar. Runners made conscious decisions to increase the amount of water consumed the night before and avoided alcoholic beverages. Runners also relied on water stations along the course to rehydrate, which is an important consideration for road race organizers when they plan an event. When compared between EDU and NED, the number of runners who changed their pre race intention and decided to drink by thirst on race day was greater than the expected value in EDU but lower in NED (Figure 1.15). The educational video may have contributed in increasing the number of runners that drank by thirst since it was listed as one of the methods runners can use to gauge on their hydration status (Appendix II). However, the lack of improvement in other behaviors that were highlighted in the educational video suggest that the greater number of runners using thirst may have resulted from chance. Furthermore, some

of the educational content in the video pertained to long-term preparation (i.e., heat acclimatization), which may not directly influence runner's race day behavior due to the timing of intervention used in the study (i.e., three days before race day). Future revisions in the educational video and KT contents with adjustment in the timing of the intervention may result in a better transfer of knowledge to runner's race day behavior.

**CONCLUSION**

$PRE_{RACE}$ survey revealed that most runners trained specifically for the 2016 Falmouth Road Race. The survey found recent illness, intake of medication and supplements, and misconceptions regarding heat illnesses and hydration practices among runners, which could present added risk for exertional heat illness or admittance to the medical tent. A short educational video improved runners' KT score, however, group difference between EDU and NED on race day behavior was only observed in use of thirst as a marker of dehydration. Further revision on the educational video may be warranted to specifically address the misconceptions and race day behaviors identified through current study.

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**Figure Legends:**

Figure 1.1. Study sequence and survey response rate at each time point (EDU, educational video intervention group; NED, control group).

Figure 1.2. Percentage of road race participants (EDU, educational video intervention group; NED, control group) that answered knowledge test questions 1–5 correctly before race ($PRE_{RACE}$), after educational video ($POST_{EDU}$), and after race ($POST_{RACE}$) (*, $p \leq 0.001$; †, $p \leq 0.01$; ‡, $p \leq 0.05$).

Figure 1.3. Percentage of road race participants (EDU, educational video intervention group; NED, control group) that answered knowledge test questions 6–10 correctly before race ($PRE_{RACE}$), after educational video ($POST_{EDU}$), and after race ($POST_{RACE}$) (*, $p \leq 0.001$; †, $p \leq 0.01$; ‡, $p \leq 0.05$).

Figure 1.4. Percentage of road race participants (EDU, educational video intervention group; NED, control group) that answered knowledge test questions 11–15 correctly before race ($PRE_{RACE}$), after educational video ($POST_{EDU}$), and after race ($POST_{RACE}$) (*, $p \leq 0.001$; †, $p \leq 0.01$; ‡, $p \leq 0.05$).

Figure 1.5. Percentage of road race participants (EDU, educational video intervention group; NED, control group) that answered knowledge test questions 16–20 correctly before race ($PRE_{RACE}$), after educational video ($POST_{EDU}$), and after race ($POST_{RACE}$) (*, $p \leq 0.001$; †, $p \leq 0.01$; ‡, $p \leq 0.05$).

Figure 1.6. Intended hydration strategies ($PRE_{RACE}$) and actual strategies used on race day ($POST_{RACE}$). Participants were allowed to choose more than one hydration strategy.

Figure 1.7. Comparison of pre-race intention (INT) and race day behavior (BHV) to avoid alcohol the night before in order to optimize race day hydration status between educational video intervention group (EDU) and control group (NED).

Figure 1.8. Comparison of pre-race intention (INT) and race day behavior (BHV) to drink ample amount of water the night before in order to optimize race day hydration status (EDU, educational video intervention group; NED, control group).

Figure 1.9. Comparison of pre-race intention (INT) and race day behavior (BHV) to carry own water bottle or pouch in order to optimize race day hydration status (EDU, educational video intervention group; NED, control group).

Figure 1.10. Comparison of pre-race intention (INT) and race day behavior (BHV) to stop at some water stations along the course in order to optimize race day hydration status (EDU, educational video intervention group; NED, control group).

Figure 1.11. Comparison of pre-race intention (INT) and race day behavior (BHV) to stop at all water stations along the course in order to optimize race day hydration status (EDU, educational video intervention group; NED, control group).

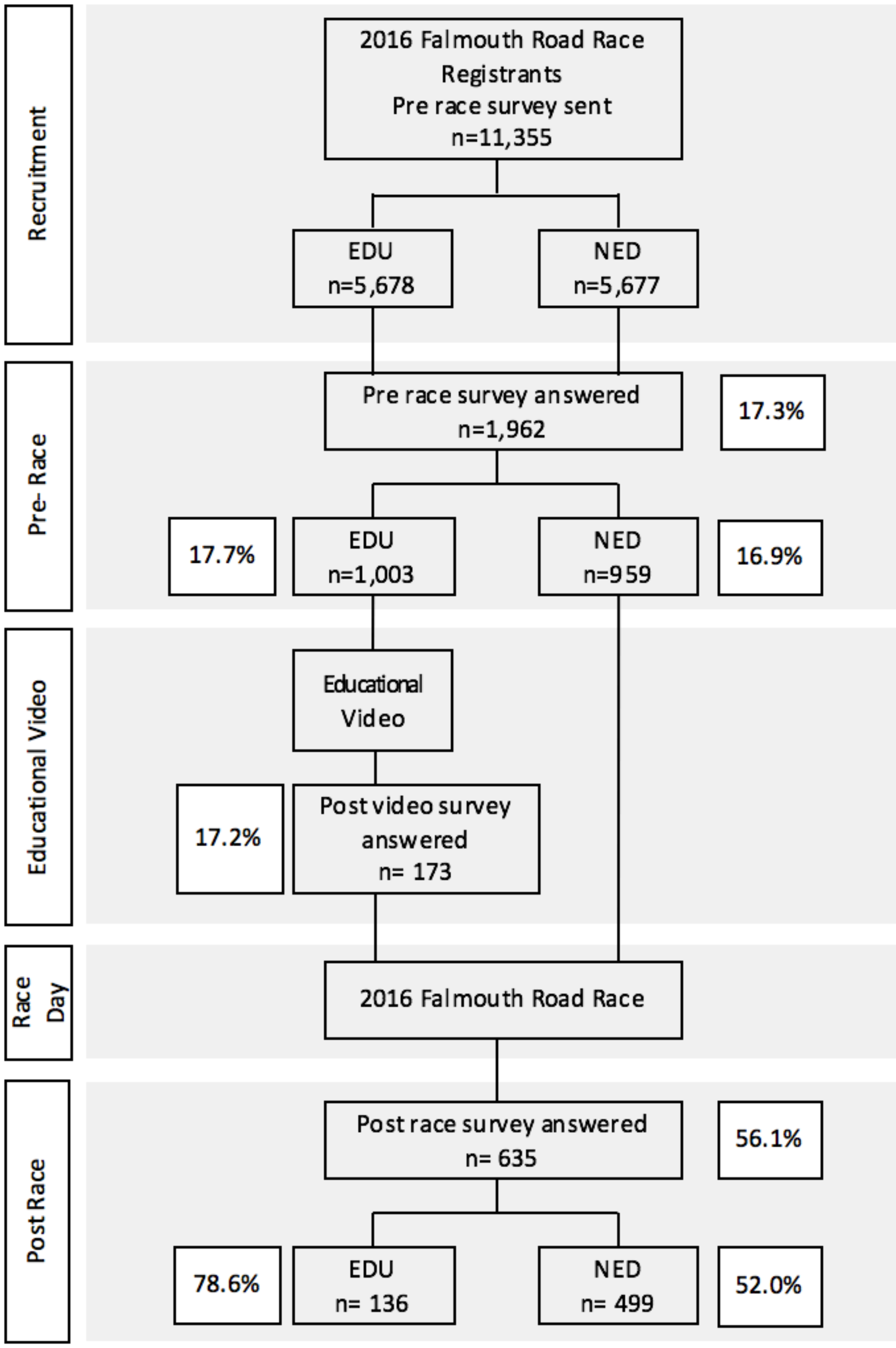
Figure 1.12. Comparison of pre-race intention (INT) and race day behavior (BHV) to drink to thirst during race in order to optimize race day hydration status (EDU, educational video intervention group; NED, control group).

Figure 1.13. Comparison of pre-race intention (INT) and race day behavior (BHV) to wait until after the race to rehydrate (EDU, educational video intervention group; NED, control group).

Figure 1.14. Comparison of pre-race intention (INT) and race day behavior (BHV) to avoid caffeinated beverages in order to optimize race day hydration status (EDU, educational video intervention group; NED, control group).

Figure 1.15. Mosaic plot illustrating the shift in intention (INT) and behavior (BHV) of runners following thirst to drink during race in order to optimize race day hydration status (EDU, educational video intervention group; NED, control group).

Figure 1.1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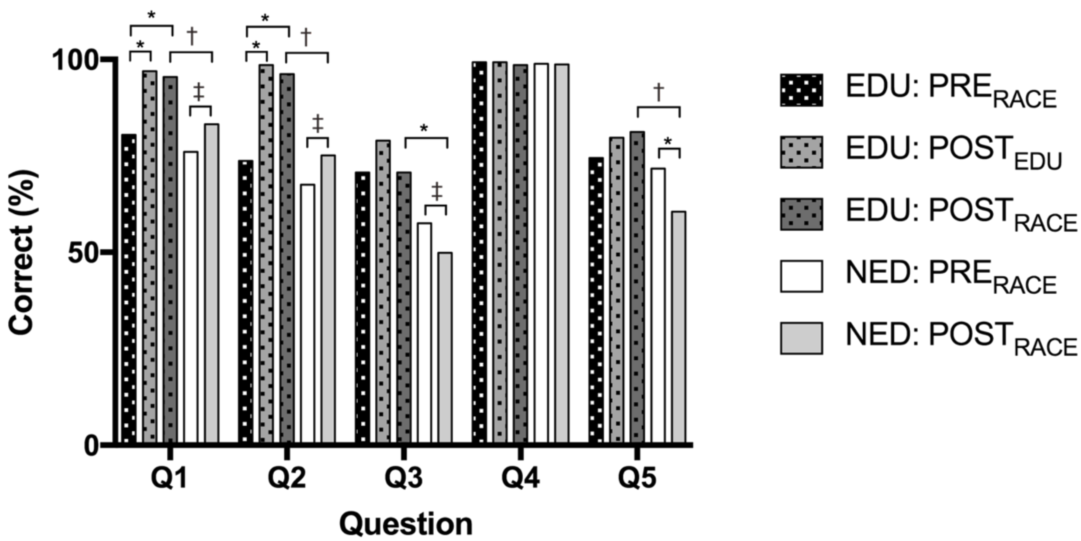
2016 Falmouth Road Race
Registrants
Pre race survey sent
n=11,355
EDU
n=5,678
NED
n=5,677
Pre- Race
Pre race survey answered
n=1,962
17.3%
17.7%
EDU
n=1,003
NED
n=959
16.9%
Educational Video
Educational
Video
17.2%
Post video survey
answered
n= 173
Race
Day
2016 Falmouth Road Race
Post Race
Post race survey answered
n= 635
56.1%
78.6%
EDU
n= 136
NED
n= 499
52.0%

Figure 1.2

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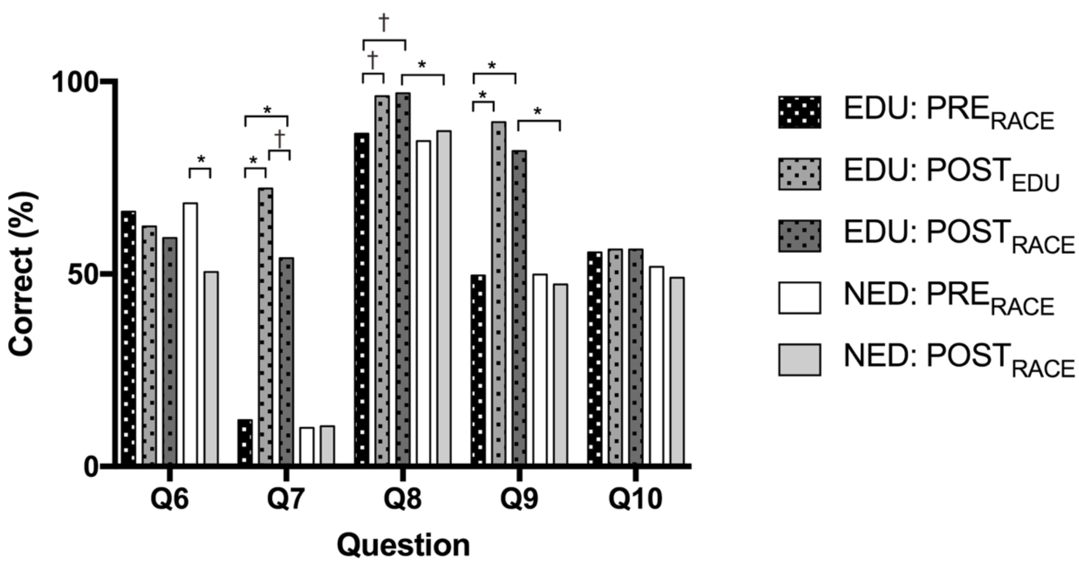

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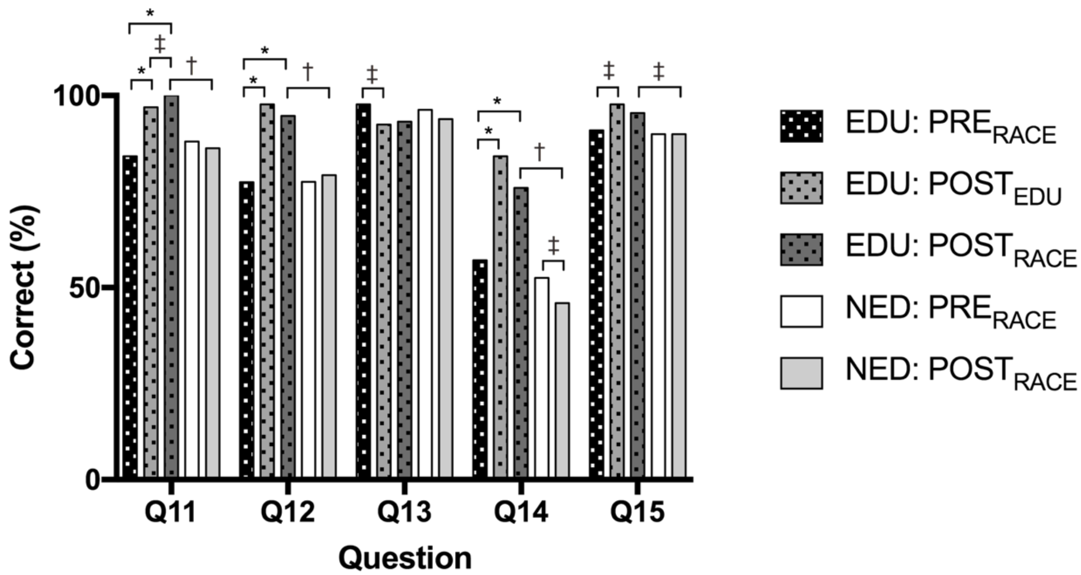


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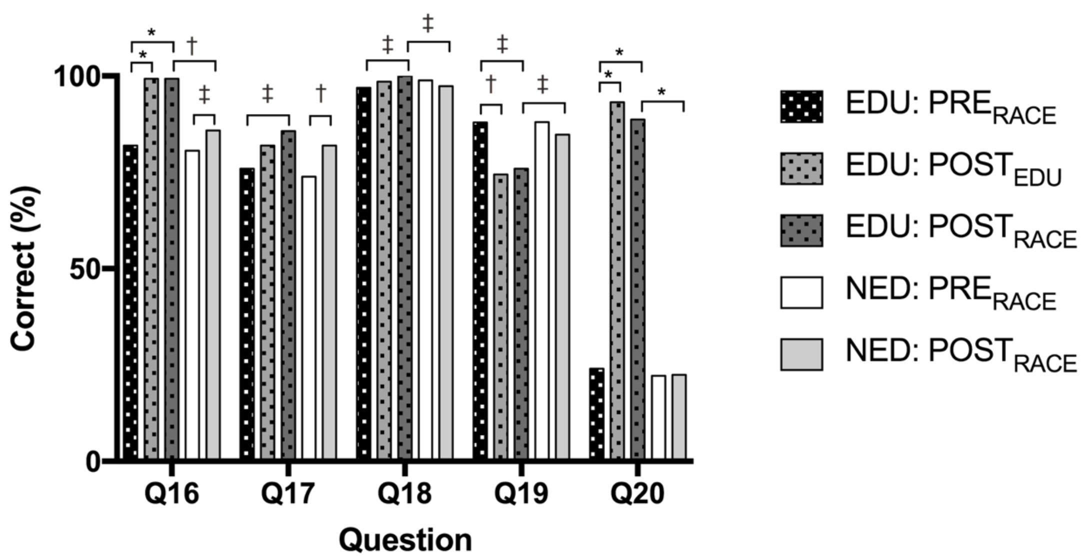

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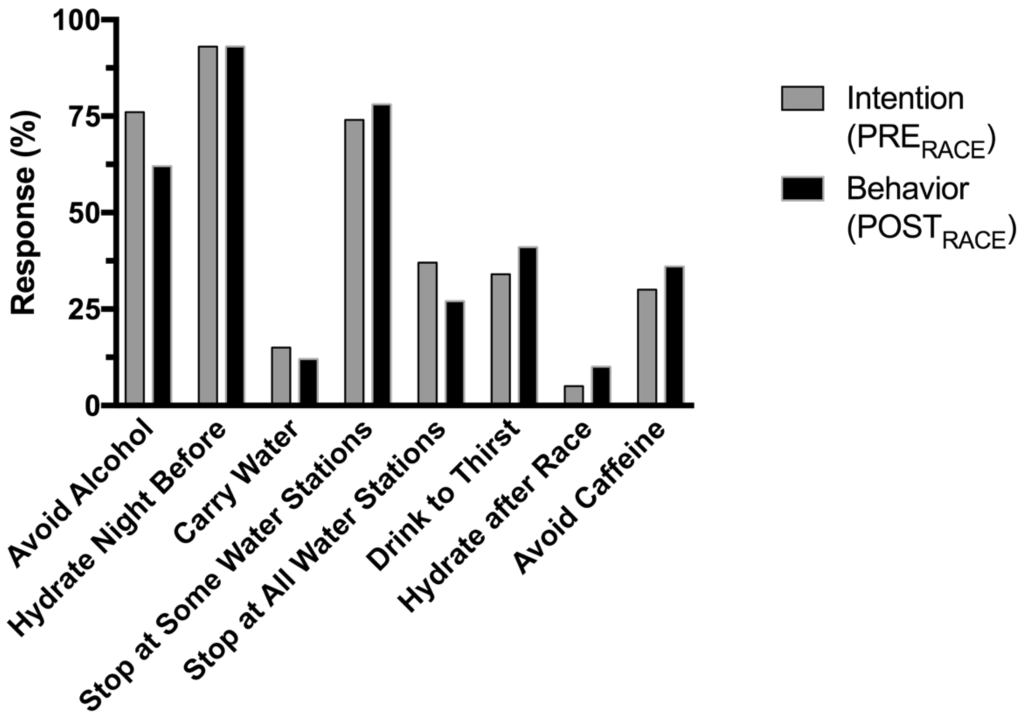


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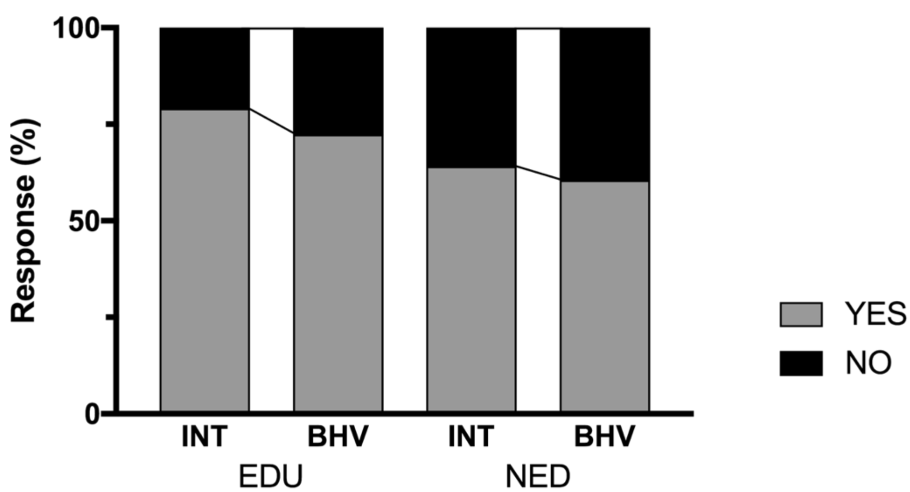

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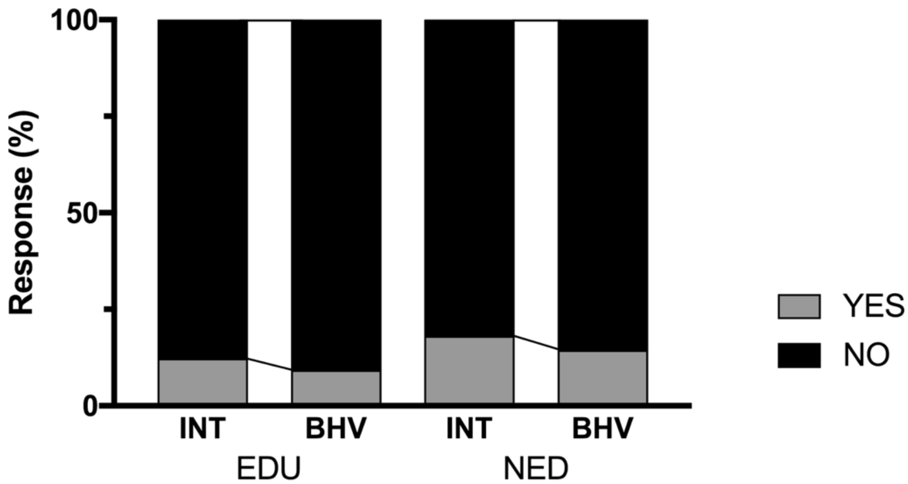


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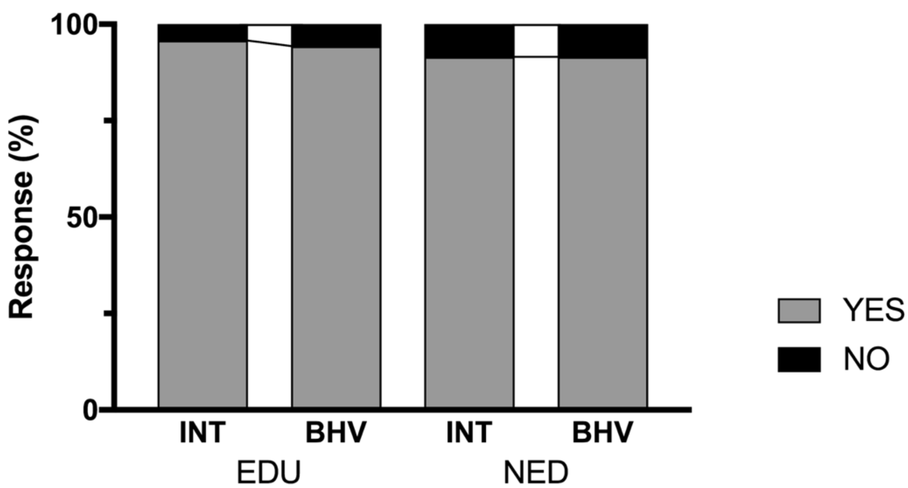

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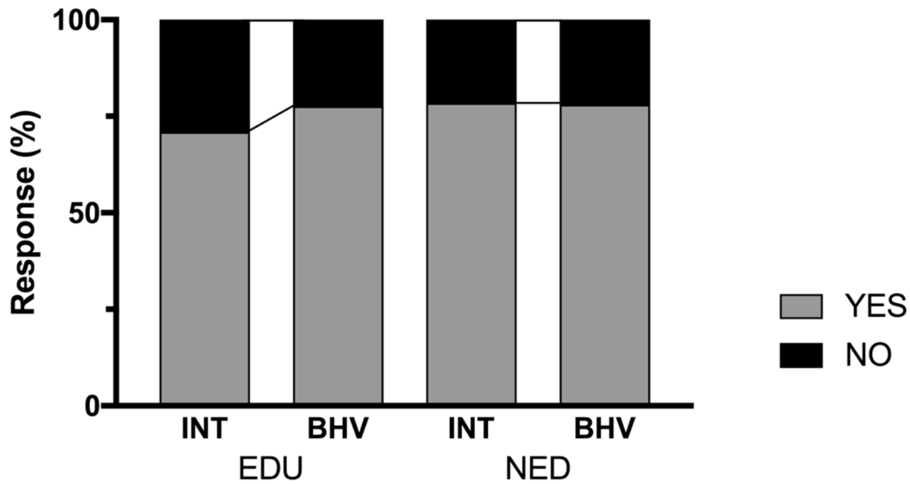


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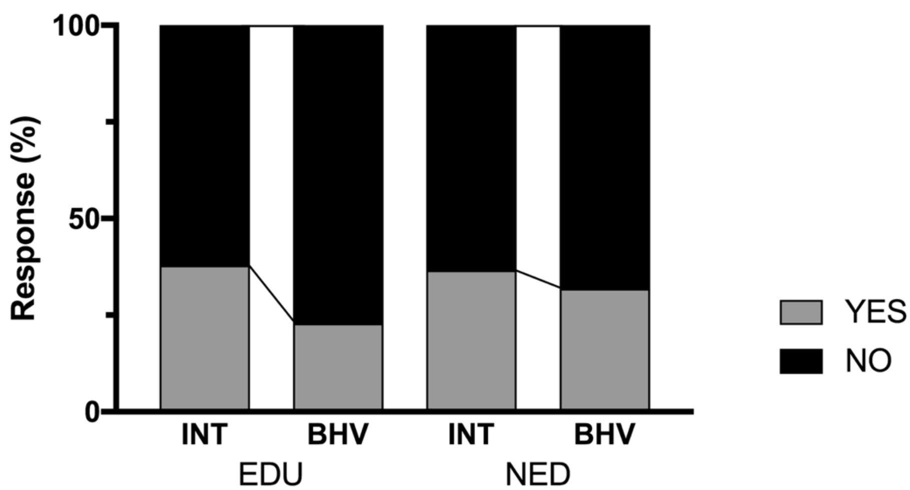

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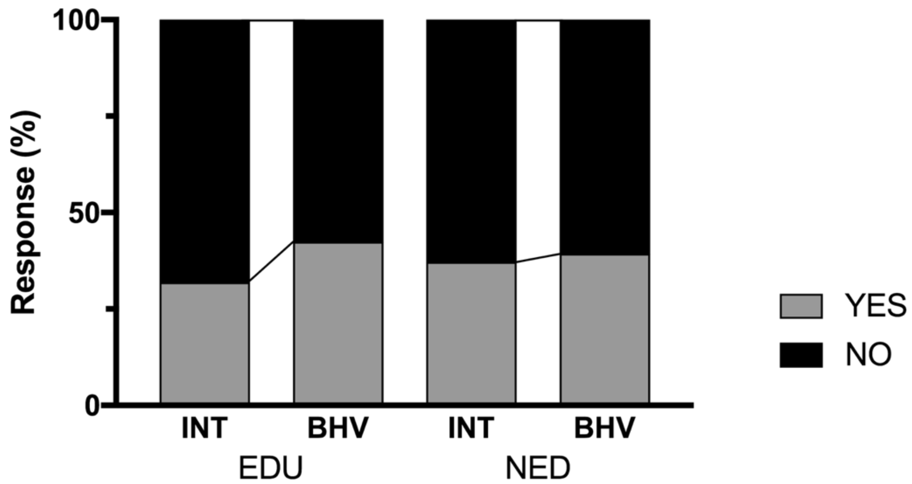


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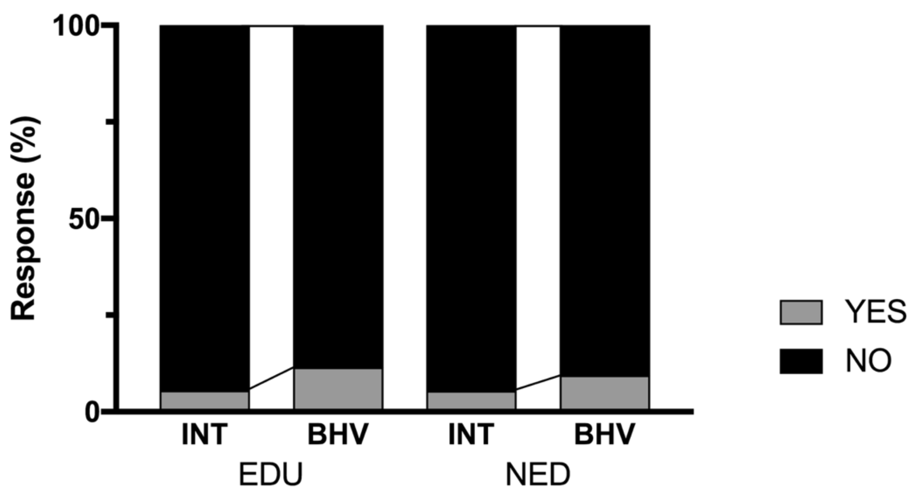

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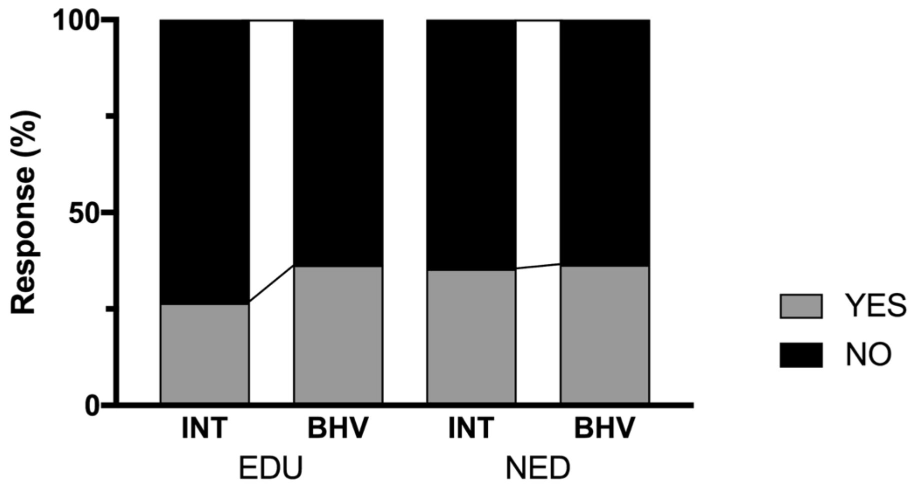


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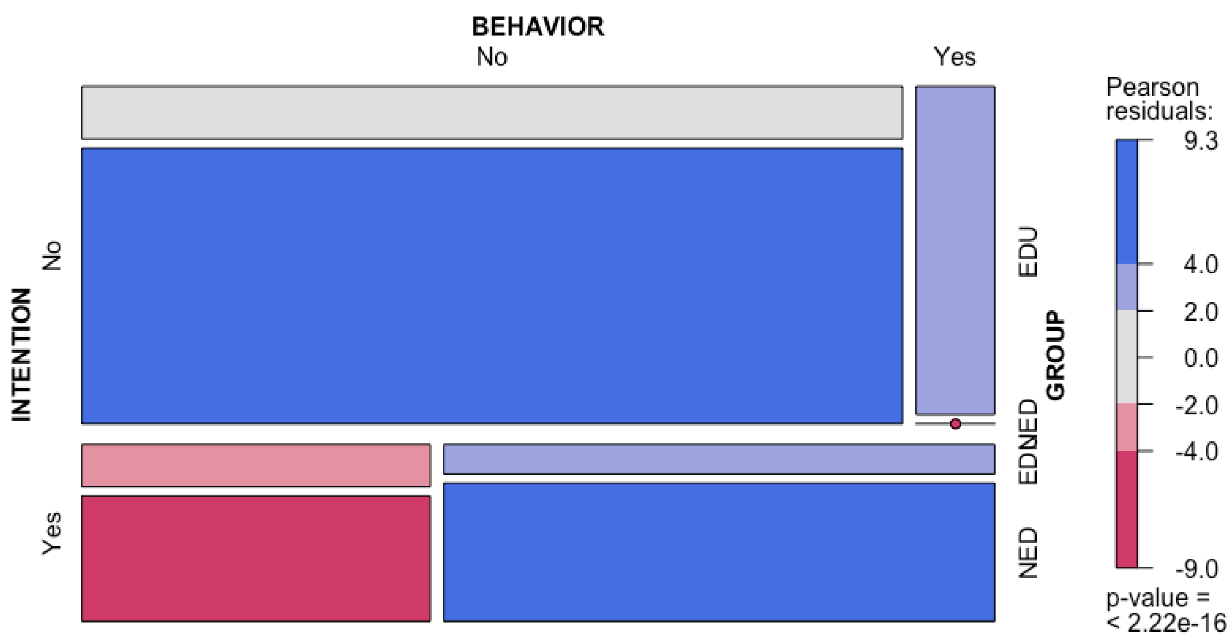

Table 1.1

Table 1.1 Study Participants' Age

| Age (years) | Pre race survey n (%) | | | | | | Post race survey n (%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | EDU | | NED | | Pooled | | EDU | | NED | | Pooled | |
| Under 20 | 29 | -2.9 | 14 | -1.5 | 43 | -2.2 | 0 | 0 | 6 | -1.2 | 6 | -0.9 |
| 20-29 | 186 | -18.5 | 178 | -18.6 | 364 | -18.6 | 17 | -12.5 | 84 | -16.8 | 101 | -15.9 |
| 30-39 | 244 | -24.3 | 210 | -21.9 | 454 | -23.1 | 30 | -22.1 | 119 | -23.8 | 149 | -23.5 |
| 40-49 | 218 | -21.7 | 225 | -23.5 | 443 | -22.6 | 42 | -30.9 | 117 | -23.4 | 159 | -25 |
| 50-59 | 168 | -16.7 | 171 | -17.8 | 339 | -17.3 | 30 | -22.1 | 89 | -17.8 | 119 | -18.7 |
| 60-69 | 74 | -7.4 | 71 | -7.4 | 145 | -7.4 | 15 | -11 | 41 | -8.2 | 56 | -8.8 |
| 70-79 | 11 | -1.1 | 6 | -0.6 | 17 | -0.9 | 1 | -0.7 | 4 | -0.8 | 5 | -0.8 |
| 80 or older | 2 | -0.2 | 2 | -0.2 | 4 | -0.2 | 0 | 0 | 1 | -0.2 | 1 | -0.2 |
| No Answer | 71 | -7.1 | 82 | -8.6 | 153 | -7.8 | 1 | -0.7 | 38 | -7.6 | 39 | -6.1 |

EDU= educational video intervention group, NED= control group

Table 1.2

Table 1.2. Participants' Sex

| | Pre race survey n (%) | | | | | | Post race survey n (%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | EDU | | NED | | Pooled | | EDU | | NED | | Pooled | |
| Male | 393 | (39.2) | 322 | (33.5) | 715 | (36.4) | 55 | (40.4) | 171 | (34.3) | 226 | (35.6) |
| Female | 535 | (53.3) | 543 | (56.7) | 1078 | (55.0) | 80 | (58.8) | 287 | (57.5) | 367 | (57.8) |
| No Answer | 75 | (7.5) | 94 | (9.8) | 169 | (8.6) | 1 | (0.7) | 41 | (8.2) | 42 | (6.6) |

EDU= educational video intervention group, NED= control group

Table 1.3

Table 1.3. Number of Falmouth Road Races Completed

| Number of Races | Pre race survey n (%) | | | | | | Post race survey n (%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | EDU | | NED | | Pooled | | EDU | | NED | | Pooled | |
| 0 | 296 | (29.5) | 297 | (31.0) | 593 | (30.2) | - | (-) | - | (-) | - | (-) |
| 1 | 99 | (9.9) | 98 | (10.2) | 197 | (10.0) | 42 | (30.9) | 171 | (34.3) | 213 | (33.5) |
| 2 | 101 | (10.1) | 79 | (8.2) | 180 | (9.2) | 24 | (17.6) | 68 | (13.6) | 92 | (14.5) |
| 3 | 95 | (9.5) | 86 | (9.0) | 181 | (9.2) | 14 | (10.3) | 43 | (8.6) | 57 | (9.0) |
| 4 | 56 | (5.6) | 62 | (6.5) | 118 | (6.0) | 7 | (5.1) | 36 | (7.2) | 43 | (6.8) |
| 5 | 63 | (6.3) | 56 | (5.8) | 119 | (6.1) | 11 | (8.1) | 28 | (5.6) | 39 | (6.1) |
| 6 | 32 | (3.2) | 27 | (2.8) | 59 | (3.0) | 3 | (2.2) | 20 | (4.0) | 23 | (3.6) |
| 7 | 28 | (2.8) | 31 | (3.2) | 59 | (3.0) | 6 | (4.4) | 13 | (2.6) | 19 | (3.0) |
| 8 | 24 | (2.4) | 15 | (1.6) | 39 | (2.0) | 1 | (0.7) | 14 | (2.8) | 15 | (2.4) |
| 9 | 5 | (0.5) | 7 | (0.7) | 12 | (0.6) | 3 | (2.2) | 6 | (1.2) | 9 | (1.4) |
| 10 | 133 | (13.3) | 119 | (12.4) | 252 | (12.8) | 24 | (17.6) | 62 | (12.4) | 86 | (13.5) |
| No Answer | 71 | (7.1) | 82 | (8.6) | 153 | (7.8) | 1 | (0.7) | 38 | (7.6) | 39 | (6.1) |

EDU= educational video intervention group, NED= control group

Table 1.4

**Table 1.4. Number of Participants with Healthcare Professional Background**

| Healthcare Professional | Pre race survey n (%) | | | | | | Post race survey n (%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | EDU | | NED | | Pooled | | EDU | | NED | | Pooled | |
| Yes | 129 | (12.9) | 125 | (13.0) | 254 | (12.9) | 26 | (19.1) | 71 | (14.2) | 97 | (15.3) |
| No | 803 | (80.1) | 752 | (78.4) | 1555 | (79.3) | 109 | (80.1) | 390 | (78.2) | 499 | (78.6) |
| No Answer | 71 | (7.1) | 82 | (8.6) | 153 | (7.8) | 1 | (0.7) | 38 | (7.6) | 39 | (6.1) |

EDU= educational video intervention group, NED= control group

Table 1.5

Table 1.5. Healthcare Professional Background

| Medical Training | Pre race survey n (%) | | | | | | Post race survey n (%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | EDU | | NED | | Pooled | | EDU | | NED | | Pooled | |
| Athletic Trainer | 2 | (1.6) | 3 | (2.4) | 5 | (2.0) | 0 | (0.0) | 3 | (4.2) | 3 | (3.1) |
| Anesthesiology | 1 | (0.8) | 0 | (0.0) | 1 | (0.4) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| Chiropractic | 1 | (0.8) | 0 | (0.0) | 1 | (0.4) | 0 | (0.0) | 0 | (0.0) | 0 | (0.0) |
| Emergency Medicine | 6 | (4.7) | 6 | (4.8) | 12 | (4.7) | 2 | (7.7) | 4 | (5.6) | 6 | (6.2) |
| General Medicine | 26 | (20.2) | 17 | (13.7) | 43 | (17.0) | 8 | (30.8) | 14 | (19.7) | 22 | (22.7) |
| Occupational Therapy | 4 | (3.1) | 6 | (4.8) | 10 | (4.0) | 2 | (7.7) | 4 | (5.6) | 6 | (6.2) |
| Paramedic | 5 | (3.9) | 2 | (1.6) | 7 | (2.8) | 0 | (0.0) | 1 | (1.4) | 1 | (1.0) |
| Pediatric | 8 | (6.2) | 10 | (8.1) | 18 | (7.1) | 0 | (0.0) | 2 | (2.8) | 2 | (2.1) |
| Pharmacology | 6 | (4.7) | 5 | (4.0) | 11 | (4.3) | 2 | (7.7) | 4 | (5.6) | 6 | (6.2) |
| Physical Therapy | 11 | (8.5) | 11 | (8.9) | 22 | (8.7) | 2 | (7.7) | 4 | (5.6) | 6 | (6.2) |
| Sports Medicine | 1 | (0.8) | 3 | (2.4) | 4 | (1.6) | 0 | (0.0) | 3 | (4.2) | 3 | (3.1) |
| Registered Nurse | 20 | (15.5) | 20 | (16.1) | 40 | (15.8) | 5 | (19.2) | 9 | (12.7) | 14 | (14.4) |
| Other | 38 | (29.5) | 41 | (33.1) | 79 | (31.2) | 5 | (19.2) | 23 | (32.4) | 28 | (28.9) |

EDU= educational video intervention group, NED= control group

Table 1.6

**Table 1.6. Number of Participants with Previous Heat Illness and Exertion Related Medical History**

| | EDU | NED | Pooled |
|---|---|---|---|
| Heat Syncope | 8 | 5 | 13 |
| Heat Exhaustion | 10 | 5 | 15 |
| Exertional Heat Stroke | 9 | 6 | 15 |
| Classic Heat Stroke | 2 | 1 | 3 |
| Rhabdomyolysis | 4 | 3 | 7 |
| Total | 33 | 20 | 53 |

EDU= educational video intervention group, NED= control group

Table 1.7

**Table 1.7. Knowledge Test Score**

| | Pre race | Post education | Post Race |
|---|---|---|---|
| EDU | 72.1 (9.4) | 87.6 (10.6) | 85.0 (10.7) |
| NED | 70.1 (9.8) | NA | 68.9 (10.0) |

EDU= educational video intervention group, NED= control group. All values in mean (SD).

## CHAPTER II. MODIFIED HEAT TOLERANCE TEST TO EVALUATE CARIOVASCULAR AND THERMAL STABIIITY DURING EXERCISE IN THE HEAT

### INTRODUCTION

Previous work suggests that cardiovascular fitness explains great proportion of one's ability to sustain cardiovascular and thermoregulatory stability in heat.[1–3] In runners who participated in a warm weather summer road race, maximal oxygen uptake ($VO_2$max) explained 86% of the variance observed in race finish time (FT).[4] However, the assessment of thermoregulatory response using an exercise protocol with a fixed intensity at runner's %$VO_2$max was critiqued due to "unintended" disadvantage for more aerobically fit individuals because they will complete at a higher-intensity of exercise that results in faster rate of rise in rectal temperature if a difference in body size is corrected.[5,6]

The most studied heat tolerance protocol, developed by the Israeli Defense Force (IDF), utilizes motorized treadmill with a fixed speed at $5km\times h^{-1}$ at 2% grade in a climatic chamber set at 40°C and 40% relative humidity (RH).[7] The test is designed to assess the readiness of exertional heat stroke patients to exercise in the heat.[8–10] However, external validity of the IDF protocol to assess athlete's readiness to exercise in the heat is debatable due to the test's relatively low exercise intensity.[11] To establish more sport specific protocol, Mee et al.[11] investigated the use of 30-minute running protocol ($9km\times h^{-1}$) on motorized treadmill at 2% grade in a climatic chamber set at 40°C and 40% RH. Although the investigation demonstrated high repeatability of the protocol in tracking peak rectal temperature ($T_{REC}$; inter correlation coefficient [ICC]=0.93), peak heart rate (HR; ICC=0.99), and peak physical strain index (PSI)[12] (ICC=0.98), it fell short in establishing a clinical threshold for a "positive" test. In addition, their study findings were limited to healthy, active, young runners. Thus, there currently is not a validated

exercise heat tolerance protocol that is tailored for varying level of runners to assess their cardiovascular and thermoregulatory stability in heat.

Therefore, this study aimed to examine the $T_{REC}$ and HR response observed during a modified heat tolerance test (mHTT) in recreational runners and to identify potential measures in assessing the heat tolerance of runner's with varying level of fitness from mHTT. Additionally, we aimed to compare internal body temperature and HR responses between a mHTT and an outdoor road race. It was hypothesized that internal body temperature and HR response from the mHTT and outdoor race would be highly correlated.

**METHODS**

A recruitment email was sent to the 2016 Falmouth Road Race registrants and volunteers provided signed informed consent. Consented subjects completed medical history, training history, and menstrual history (females) questionnaires, which were screened and approved by the medical safety monitor before study participation.

*Laboratory Test*

Participants completed a $VO_2$max test and a mHTT at the Human Performance Laboratory at the University of Connecticut (Storrs, CT) 12 to 24 days preceding to the day of the race. Participants were instructed to come to the testing euhydrated (urine specific gravity [USG] ≤1.020). Upon arrival to the laboratory, nude body mass (BM), height, skin fold measurements, and urine sample were collected. $VO_2$max test was completed on a treadmill (NordicTrack, Logan, UT) at 2% incline in room temperature (ambient temperature [$T_A$], 22.9±1.1°C; relative humidity [RH] 39±3.9%). The test began at 80% of the runner's five-kilometer race speed and the speed was increased in 0.5mph increment every three minutes until the participant reached volitional fatigue or respiratory exchange ratio of 1.1 or greater. After completing $VO_2$max testing, participants rested for at least 30-minute before starting the mHTT. Participants were allowed to consume fluid during the rest period and nude BM was measured again prior

to the start of mHTT. mHTT was conducted in an environmental chamber set at $T_A$ 40°C and 40% RH (wet bulb globe temperature [WBGT], 32.3±0.6°C). Participants completed a 30-minute run on a treadmill set at 2% incline at 60% of the velocity at $VO_2$max ($vVO_2$max). During mHTT, $T_{REC}$ (Model 401, Measurement Specialties, Hampton, VA) and HR (TICKR X Workout Tracker with Memory, Wahoo Fitness, Atlanta, GA) were collected every 2.5 minutes. The test was complete when the participant finished the 30-minute run, or terminated when the participant reached volitional fatigue to stop or $T_{RE}$ reached 39.99°C.

PSI was calculated using equation [Eq. 1], where $T_{REC_0}$ and $HR_0$ are measurements taken at the baseline, whereas $T_{REC_x}$ and $HR_x$ are measurements taken at min $x$.

$$PSI = 5\left(T_{REC_x} - T_{REC_0}\right) \cdot \left(39.5 - T_{REC_0}\right)^{-1} + 5\left(HR_x - HR_0\right) \cdot \left(HRmax_{VO_2max} - HR_0\right)^{-1} \text{ [Eq. 1]}$$

Adjustment was made from the original equation proposed by Moran et al.[12] by setting the upper threshold for the HR rise to each subject's maximal HR observed during the $VO_2$max test ($HRmax_{VO_2max}$). External work (W) completed by each participant during mHTT was calculated from BM, treadmill velocity (V; $m \cdot min^{-1}$), fractional grade of the treadmill ($F_{GR}$), and body surface area (BSA).[13,14] [Eq. 2]

$$W = 0.163 \cdot BM \cdot V \cdot (F_{GR} \,/\, BSA) \text{ [Eq. 2]}$$

Percent BM loss (%BML) and sweat rate (SR; $L \cdot hr^{-1}$) were calculated from the difference between pre and post exercise BM.

### *Training Log and Surveys*

Participants logged their training using a phone application (wahoo FITNESS, Wahoo Fitness, Atlanta, GA) or in an electronic sheet during the four weeks leading up to race day. The training log

included date, time, location, duration, distance of any run training sessions. Participants were also asked to complete a survey during the three days before race day ($PRE_{RACE}$) and in the afternoon of the race day after they completed the race ($POST_{RACE}$).

*Field Test*

Participants swalloed an ingestible thermistor (HQ Inc., Palmetto, FL) before going to sleep the night before the race. In the morning of the race day, participants donned a waistband with a data recorder, CorTemp ELITE (HQ Inc., Palmetto, FL), and carried their iPhone (Apple Inc., Cupertino, CA) in an arm band during the race to allow for continuous recording of their $T_{GI}$ via a phone application (CorTemp, HQ Inc., Palmetto, FL). Participants also donned a HR monitor (TICKR X Workout Tracker with Memory, Wahoo Fitness, Atlanta, GA), which was also synchronized with a phone application for continuous data recording (wahoo FITNESS, Wahoo Fitness, Atlanta, GA). Race day morning data collection included BM with minimal clothing (i.e., remove shoes and shirt) and a urine sample. Female participants also completed a menstrual status questionnaire. Post race data collection included BM with minimal clothing, a urine sample, and completion of a questionnaire on fluid consumption during the race. Race time was recorded by the timing chips distributed by the Falmouth Road Race. The average $T_A$, RH, and WBGT were collected by the finish line during the race (Kestrel 5400, Nielsen-Kellerman, Boothwyn, PA).

*Statistical Analysis*

All statistical analyses were completed using SPSS (version 21; IBM Corporation, Armonk, NY). Parametric data are reported in mean±standard deviation (SD). Mean difference (MD) and 95% confidence interval (CI) are reported for group mean comparisons using two-tailed, sample t test and two-tailed, paired sample t test. Median and range are reported for nonparametric data. Change in $T_{REC}$, $T_{GI}$,

HR, and PSI across time during mHTT and across distance on race day were assessed using a two-way (measurement x Time or Distance) repeated measures ANOVA. Tukey's post-hoc analysis was used to identify pairwise differences. Statistical significance was set at $p<0.05$. Simple linear regression was used to identify factors that are associated with end PSI in mHTT and to evaluate if variables collected from mHTT were associated with $T_{GI}$ on race day. Pearson's product-moment correlation coefficients were calculated to examine correlations between end PSI at mHTT and race day.

## RESULTS

### *Study Participants*

Thirty-four runners were enrolled to the study (male runners, *n*=22; female runners, *n*=12). Characteristics of study participants are summarized in Table 2.1. Six female participants had regular menstrual cycles and 6 female participants did not have menstrual cycles from the use of long-acting contraceptive (*n*=3), hysterectomy (*n*=2), or menopause (*n*=1). The median number of road races completed by participants in the past 12 months was 5 (range, 1–23). Participants self-reported their activity level as vigorously active (i.e., heavy exercise; *n*=28) or moderately active (i.e., occasional exercise; *n*=6).

Most of the participants trained in New England (*n=28*), while others trained in Mid Atlantic (*n*=4) and South Atlantic (*n*=2). The median number of training sessions during the four weeks leading up to the day of the race was 19 (range, 6–35) (Figure 2.1). Sixty-six percent of the recorded training sessions included running (median number of running sessions per participant, 13; range, 2–31) with 94% of them outdoors (median number of running sessions in outdoor per participant, 12; range, 0–31). Most popular time to exercise was in the evening (5–8pm), followed by mid-morning (7–9am) and early-morning (4–7am) (Figure 2.2).

*Rectal Temperature and Heart Rate Responses in Modified Heat Tolerance Test*

Thirty-one participants competed the full 30-minute mHTT. Two participants discontinued due to volitional fatigue (19.67min and 16.75min), and one participant was discontinued (25min) due to sustained high HR greater than the age predicted max (210-age) for longer than 5 minutes. $T_{REC}$ ($F$[2.62, 28.78]=194.39; $p$<0.001) and HR ($F$[1.05, 20.93]=2.52; $p$=0.127) increased during the course of mHTT (Figures 2.4). Rate of rise in $T_{REC}$, M, %BML, and SR are summarized in Table 2.2. There was no difference in the rate of rise in $T_{REC}$ between the first and last 15 minutes of mHTT (MD[95%CI]=-0.008 [-0.017, 0.0005]; $p$=0.065). Linear regression analysis showed BM ($R^2$change, 0.23; β, -0.93; $p$=0.009), BSA ($R^2$change, 0.12; β, 0.56; $p$=0.053), and $VO_2$max ($R^2$change, 0.12; β, 0.46; $p$=0.047) explain 48% of the variance observed in the $T_{REC}$ gain at the end of mHTT (F[3, 27]=2.722, $p$=0.064). At the end of mHTT, participants reached 94.2±4.9% of their maximal HR observed at the $VO_2$max testing. Mean end mHTT PSI was 7.89 (range, 5.95–9.95) (Figure 2.5). The distribution of end mHTT PSI exhibited normal distribution using Shapiro-Wilk test (*df*, 30; p=0.52). Linear regression analysis showed no correlation between end mHTT PSI and BM ($p$=0.358), BSA ($p$=0.863), and VO2max ($p$=0.796).

*Gastrointestinal Temperature and Heart Rate Responses during Race*

Race day $T_A$, RH, and WBGT were 25.0±1.2°C, 70.2±5.3%, and 25.8±1.1°C, respectively. Race day USG, %BML, and SR are summarized in Table 2.3. USG at pre race was greater than mHTT, although still in the range of euhydration (MD[95%CI]=0.004 [0.002, 0.006]; $p$<0.001). Pre race BM did not differ from the mHTT (MD[95%CI]=-1.831 [-5.688, 2.027]; $p$=0.341). SR was greater at mHTT than race day (MD[95%CI]=-0.2678 [-0.532, -0.003]; $p$=0.047). The average race FT was 60.9±11.1min (male, 58.9±11.7min; female, 64.6±9.2min). Participants with greater $VO_2$max had faster race FT ($p$=0.022). $T_{GI}$ data from fourteen participants were excluded due to signaling error of the device at pre or

post race measurement. The average rise in $T_{GI}$ from pre to post race was 2.49±0.88°C (95%CI=[-2.905, -2.082]; $p$<0.001) (Figure 2.6).

HR data were collected throughout the race for 23 participants (male runner, 16; female runner, 7), which showed increase across distance covered ($F$[2.28, 50.09]=248.58; $p$<0.001) (Figure 2.7). At the end of the race, participants reached 101.2±6.3% of their maximal HR recorded in the $VO_2$max. Continuous $T_{GI}$ data were also collected throughout at race for nine participants (male runner, 7; female runner, 2). $T_{GI}$ increased across distance ($F$[1.35, 10.82]=53.38; $p$<0.001) (Figure 2.8). PSI at each kilometer was calculated for eight participants (male runner, 6; female runner, 2), which also increased across distance ($F$[1.52, 10.62]=48.10; $p$<0.001) (Figure 2.9).

*Comparison of Temperature and Heart Rate Responses in Modified Heat Tolerance Test and Race*

Only 24 % of the variance observed in the post race $T_{GI}$ was explained by end mHTT $T_{REC}$ ($p$=0.216). In addition, only 11.2 % of the variance observed in rate of rise in $T_{GI}$ on race day was explained by rate of rise in $T_{REC}$ from mHTT ($p$=0.188). Furthermore, only 21% of the variance observed in post race HR was explained by end mHTT HR ($p$=0.047).

End PSI from mHTT and post race PSI were compared in eleven participants (male runner, 8; female runner, 3) who had body temperature ($T_{REC}$, $T_{GI}$) and HR data from both days. Mean PSI at end mHTT and post race were 7.9±1.0 and 10.4±2.2, respectively (Figure 2.10). No correlation was observed between end mHTT PSI and post race PSI ($p$=0.577). Four runners showed ≥50% increase in PSI on race day compared to mHTT and five runners had PSI ≥10 on race day (Figure 2.10). No variables collected at mHTT was successful in detecting runners with ≥50% increase in PSI and PSI ≥10 on race day using simple linear regression ($p$>0.05).

## DISCUSSION

Despite the known limitation in using %$VO_2$max to evaluate thermoregulatory response[5,6], 60% $VO_2$max was chosen for the mHTT intensity due to the practical ease in identifying a running speed adjusted for each runner's aerobic capacity. The study participants represented a wide range of age (21–64 years old), $VO_2$max (33.5–62.3 ml·kg$^{-1}$·min$^{-1}$), and FT (47.3–93.5min), which makes it difficult to set a fixed test speed that provides comparable physical strain across all participants. We observed a wide range of metabolic heat production (Table 2.2), which is highly influenced by the participant's BM (Eq. 2). Therefore, it was anticipated that the variance observed in the $T_{REC}$ gain at the end of mHTT was influenced by BM. However, the correlation with $T_{REC}$ gain was weakened when PSI was used to quantify the thermal strain at end mHTT.

No strong associations were observed in internal body temperature, heart rate, and PSI response from a mHTT and race day. This is likely to due to the difference in environmental conditions, which would influence the amount of heat exchange through convection, radiation, and evaporation.[16,17] Moreover, data lost on race day reduced the statistical power to compare race day observations with data from mHTT. Nevertheless, laboratory trials that simulate the race day environmental conditions or race exercise intensity, or both, may allow researchers to elucidate a correction factor to improve the assessment of race day response from the laboratory result.

Increased running speed was linearly related to the end mHTT PSI and post race PSI ($Y$=0.9971*$X$+2.987; $R^2$=0.356; $p$<0.001). When participants who experienced ≥50% increase from end mHTT PSI to post race PSI ($n$=4) were evaluated, their post race PSI were three standard error (SE) above remaining samples ($Y$=0.6437*$X$+4.556; SE, 0.64±0.15) (Figure 2.11). This may indicate that these four participants experienced cardiovascular and thermal strain that is drastically greater than the expected value at a given running speed. Since PSI was not influenced by participant's BM, BSA, and $VO_2$max, PSI may be a factor that is worthy of further investigation when assessing cardiovascular and thermoregulatory stability during exercise in the heat. For example, divergence of the end exercise PSI

from the expected value in healthy runners may serve as the diagnostic criteria. However, it should be noted that PSI is a simplistic measure of thermal strain. Therefore, development of a more complex thermal strain index is warranted as we accumulate more data from the mHTT and outdoor road races.

**CONCLUSION**

The heat tolerance test developed by the IDF is the only validated protocol currently used by researchers and clinicians. However, the external validity for assessing one's readiness to exercise in heat in athletics population has been questioned because of low exercise intensity used in the protocol. We proposed that a 30-minute mHTT using a running speed of 60% vVO2max on a treadmill set at 2% incline in 40°C and 40% RH would provide a better representation of exercise intensity for runners. The mHTT induced progressive increase in $T_{REC}$ and HR, and the end mHTT PSI calculated from $T_{REC}$ and HR tracked thermal strain independent from the participant's BM, BSA, and $VO_2$max, with a normal distribution. However, internal body temperature, HR, and PSI response from the mHTT and outdoor 11km road race did not demonstrate strong association. The difference in environmental conditions and exercise intensity between the laboratory and outdoor testing limited mHTT's ability to identify internal body temperature and HR response that are associated with poor control of internal body temperature and HR during the outdoor race.

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**Figure Legends**:

Figure 2.1. Distribution of total training sessions completed during four weeks preceding the 2016 Falmouth Road Race.

Figure 2.2. Distribution of training session time of the day.

Figure 2.3. Intended hydration strategies ($PRE_{RACE}$) and actual strategies used on race day ($POST_{RACE}$). Participants were allowed to choose more than one hydration strategy.

Figure 2.4. Rectal temperature (●) and heart rate (■) response during a modified heat tolerance test (**, $p$<0.001).

Figure 2.5. Physical strain index (PSI) during a modified heat tolerance test ($n$=31).

Figure 2.6. Gastrointestinal temperature measured at pre race (Pre) and immediate post race (Post) (**, $p$<0.001).

Figure 2.7. Race heart rate response ($n$=23) (**, $p$<0.001).

Figure 2.8. Race gastrointestinal temperature response ($n$=9) (**, $p$<0.001).

Figure 2.9. Race physical strain index (PSI) (*n*=9).

Figure 2.10. Comparison of end physical strain index (PSI) measured during a modified heat tolerance test (mHTT) and at the Falmouth Road Race (FRR). Four runners showed ≥50% increase in PSI at FRR compared to mHTT (lines in black).

Figure 2.11. Four participant who experienced ≥50% increase in end race physical strain index (PSI) from their end modified heat tolerance PSI showed values that are three standard error greater from the simple linear regression derived from the remaining samples.

Figure 2.1

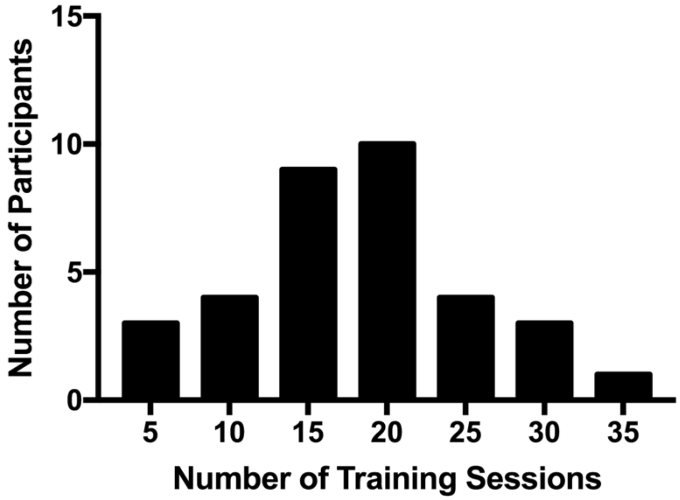



Figure 2.2

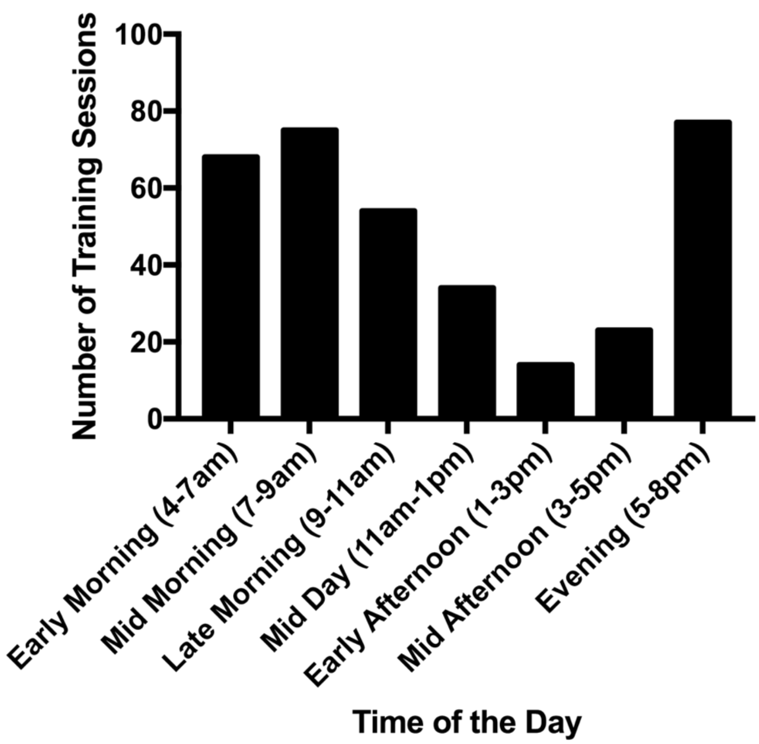
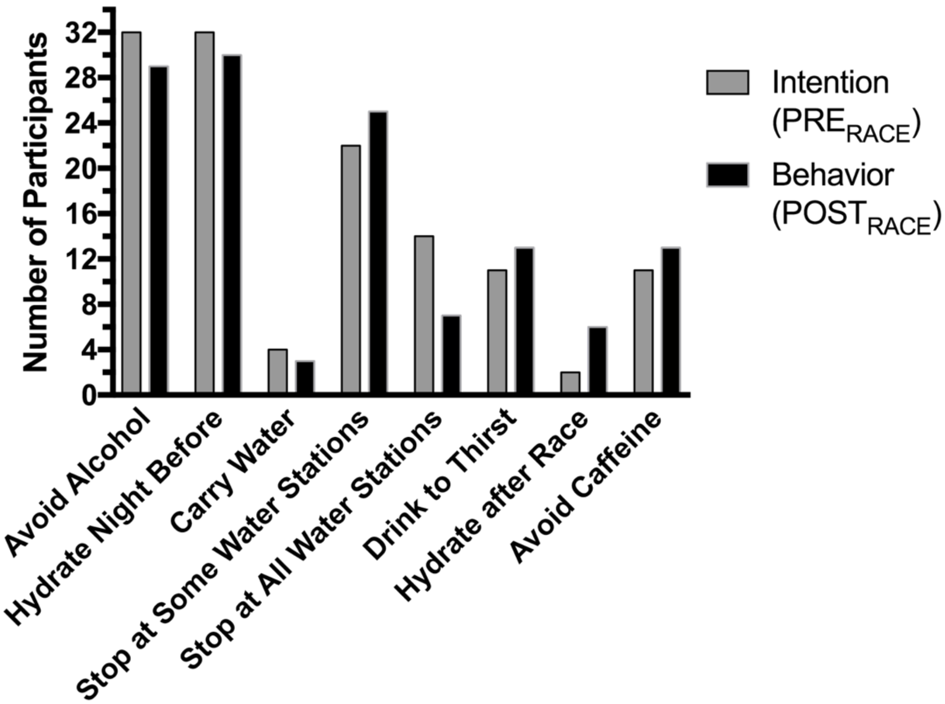


Figure 2.3

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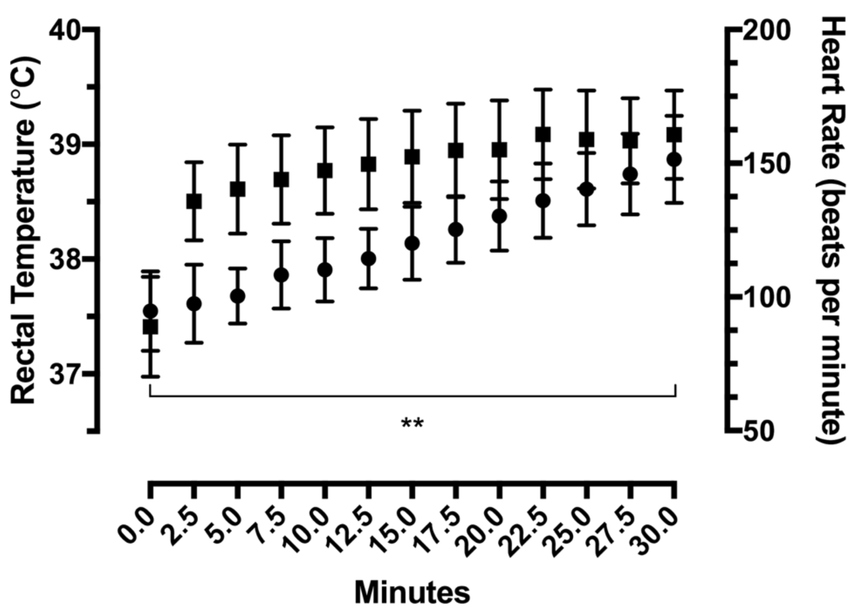

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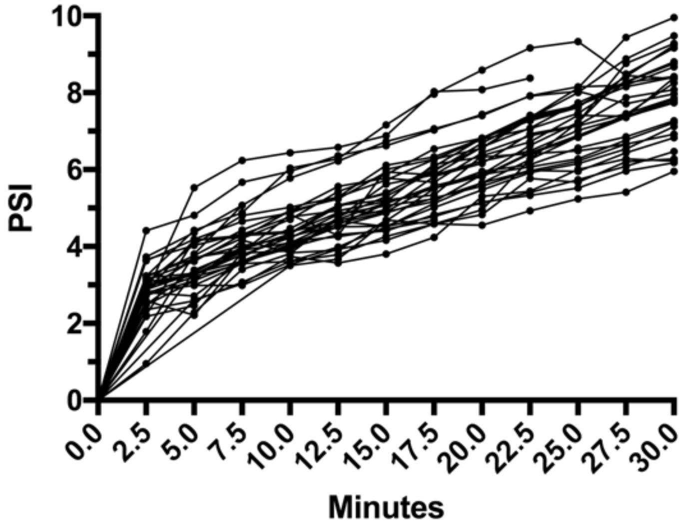


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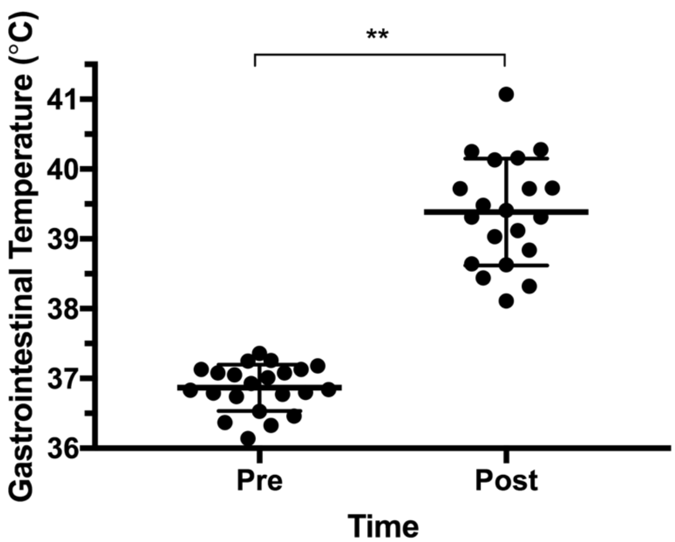

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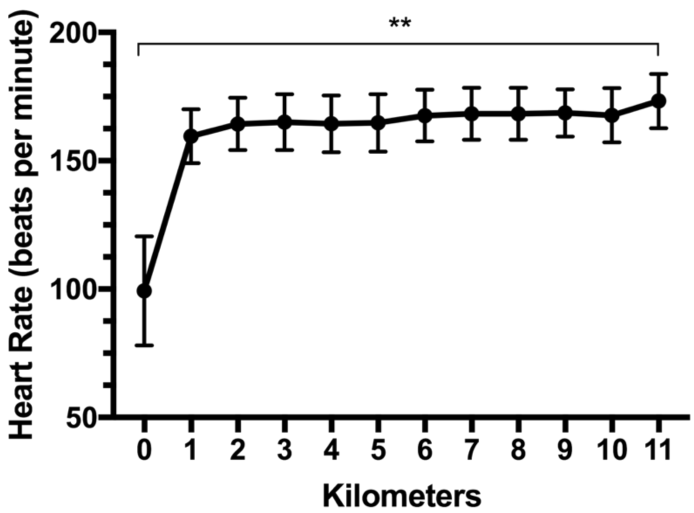


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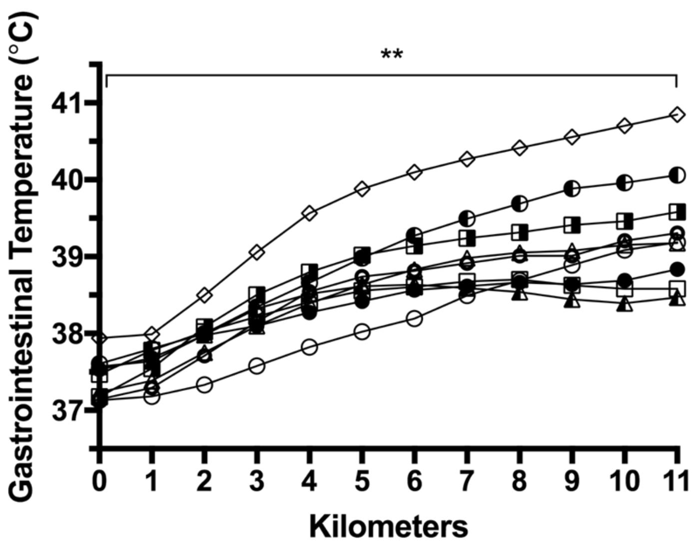

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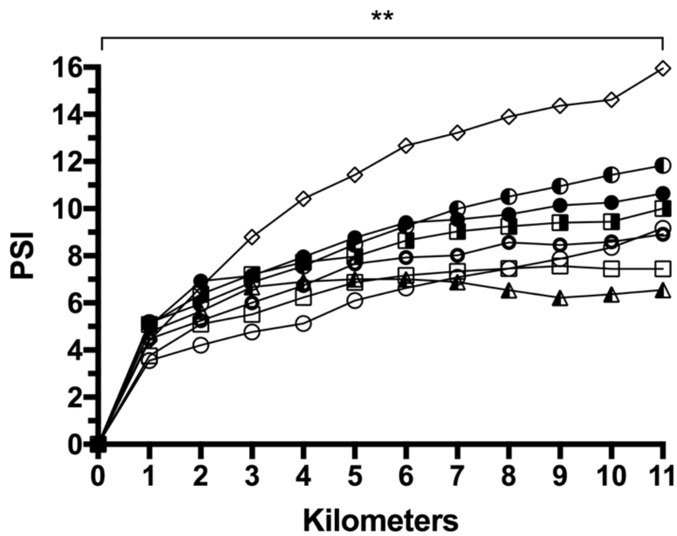


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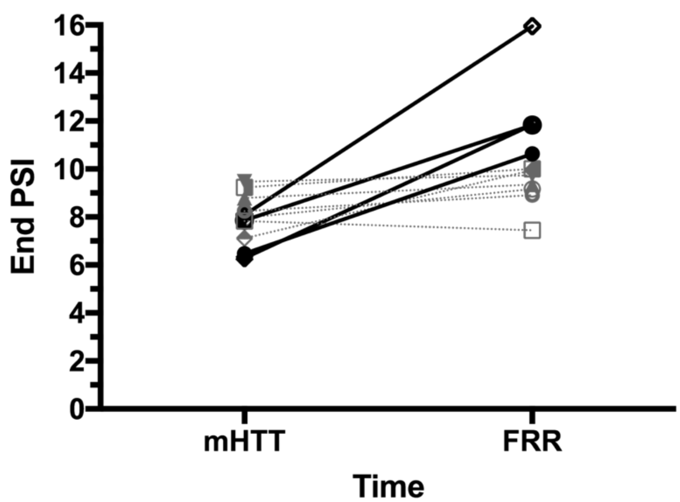

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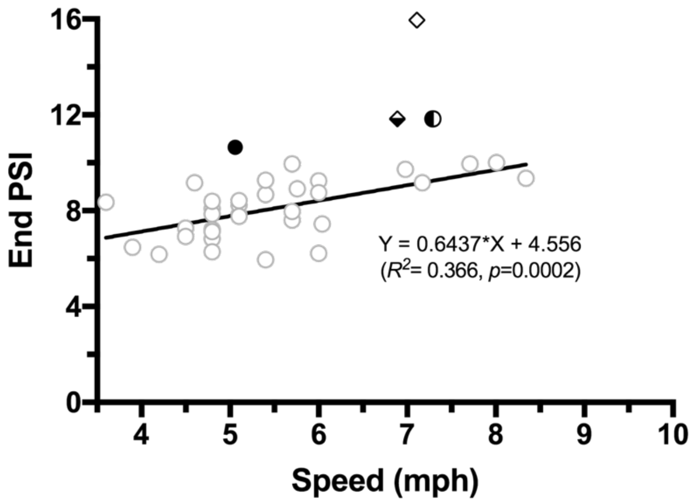

End PSI
16
12
8
4
0
4
5
6
7
8
9
10
Speed (mph)
Y = 0.6437*X + 4.556
($R^2$= 0.366, $p$=0.0002)

Table 2.1

**Table 2.1. Study Participants**

| | Male runners | Female runners | Overall |
|---|---|---|---|
| *n* | 22 | 12 | 34 |
| Age, year | 43 ± 12 | 41 ± 12 | 42 ± 12 |
| Height, cm | 178 ± 6.6 | 168.5 ± 5.6 | 174.9 ± 7.9 |
| Body mass, kg | 78.9 ± 13.1 | 67.8 ± 9.3 | 75.0 ± 12.9 |
| Body fat, % | 12.9 ± 5.6 | 18.3 ± 3.3 | 14.8 ± 5.5 |
| BSA, $m^2$ | 1.97 ± 0.16 | 1.77 ± 0.13 | 1.90 ± 0.18 |
| $VO_2$ max, $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ | 45.2 ± 7.0 | 38.0 ± 5.9 | 42.6 ± 7.4 |
| $vVO_2$ max, mph | 8.7 ± 1.1 | 7.5 ± 1.0 | 8.3 ± 1.2 |

BSA= body surface area, $VO_2$ max= maximal oxygen consumption, $vVO_2$ max= velocity at maximal oxygen consumption. All values in mean ± SD.

Table 2.2

**Table 2.2 Summary Data from a Modified Heat Tolerance Test**

| | Male runners | Female runners | Overall |
|---|---|---|---|
| Rate of rise in the first 15 minutes, $°C{\cdot}min^{-1}$ | 0.040 ± 0.015 | 0.038 ± 0.024 | 0.039 ± 0.019 |
| Rate of rise in the last 15 minutes, $°C{\cdot}min^{-1}$ | 0.048 ± 0.017 | 0.047 ± 0.018 | 0.048 ± 0.017 |
| External work, $W{\cdot}m^2$ | 1056 ± 126 | 887 ± 81 | 996 ± 138 |
| Body mass loss, % | 1.3 ± 0.4 | 1.3 ± 0.4 | 1.3 ± 0.4 |
| Sweat rate, $L{\cdot}hr^{-1}$ | 2.1 ± 0.6 | 1.9 ± 0.4 | 1.9 ± 0.6 |

All values in mean ± SD.

Table 2.3

**Table 2.3. Summary Data from Race Day**

| | Male runners | Female runners | Overall |
|---|---|---|---|
| Pre race urine specific gravity | 1.014 ± 0.006 | 1.010 ± 0.005 | 1.012 ± 0.006 |
| Post race urine specific gravity | 1.009 ± 0.007 | 1.008 ± 0.004 | 1.009 ± 0.006 |
| Body mass loss, % | 2.1 ± 0.9 | 1.1 ± 0.4 | 1.8 ± 1.0 |
| Sweat rate, $L{\cdot}hr^{-1}$ | 2.0 ± 0.8 | 1.1 ± 0.7 | 1.7 ± 0.9 |

All values in mean ± SD.

# CHAPTER III. EXERTIONAL HEAT STROKE CASE SERIES: RISK FACTORS ASSOCIATED WITH INCIDENCE OF EXERTIONAL HEAT STROKE

## INTRODUCTION

Exertional heat stroke (EHS) is one of the top three leading causes of death in physical activity. Researchers have investigated the risk factors of EHS through a retrospective analysis of EHS cases in military recruits, American football players, and runners.[1–5] Previous literature suggests that lack of heat acclimatization, previous history of heat related illness, low fitness, lack of sleep, recent illness, large body mass, high motivation, high or unmatched exercise intensity to one's capacity, dehydration, and lack of awareness and/or education may increase one's risk for EHS.[1–7] Recent research also suggests that there may be a genetic predisposition for certain individual to experience uncontrolled hyperthermia with exercise.[5,8] However, the specificity and sensitivity of each risk factor to detect the risk for EHS is currently unknown since previous case studies failed to examine the prevalence of aforementioned factors in a cohort of individuals who did not experience EHS from the same physical activity.

The clinical definition of EHS is exertional hyperthermia (internal body temperature ≥40-40.5°C) with a manifestation of central nervous system (CNS) dysfunction.[6,7] During exercise, especially under warm environment and/or at high physical exertion, it is not uncommon for the internal body temperature to rise above the diagnostic threshold for EHS.[9,10] These individuals do not present CNS dysfunction and are able to regulate their body temperature back to normothermia after they cease exercise.[10] The underlining reason as to why these runners are able to thermoregulate while others result in EHS after completing the same physical exertion is unknown.

Therefore, we aimed to profile EHS patients from the 2016 Falmouth Road Race in a case series format with prospectively collected information on their pre-race behavior, their knowledge on heat safety and hydration, and their clinical presentation from race day. A cohort of runners who experienced

exercise-induced hyperthermia (EIH; ≥40°C) from the same race was investigated as a comparison group to elucidate factors that may be associated with EHS. Subsequent analysis also aimed to compare EHS runners with runners who were not admitted to the medical tent for EHS on race day (CON). It was hypothesized that EHS will present with more risk factors than EIH and CON.

## METHODS

### *Survey*

Pre race ($PRE_{RACE}$) and post race ($POST_{RACE}$) surveys were sent to the registrants of 2016 Falmouth Road Race (Falmouth, MA), an 11-kilometer summer road race, to investigate their sex, age, medication and supplement intake, number of Falmouth Road Races completed, hours of sleep, recent illness, history of exertional heat illness, and their level of motivation going into the race (*"I am highly motivated to achieve my personal best and/or to run faster than other race participant(s) at this year's race"*; 1, strongly disagree; 2, somewhat disagree; 3, neither agree nor disagree; 4, somewhat agree; 5, strongly agree). Participant's knowledge on heat safety and hydration strategies in the heat (knowledge test, KT) was also assessed in $PRE_{RACE}$ and $POST_{RACE}$ (Appendix I). This was part of a larger cohort study that was conducted at the 2016 Falmouth Road Race. Runners were informed that participation was voluntary and were asked to provide a consent to release their survey answers to be cross referenced with the medical tent information.

### *Exertional Heat Stroke Runners*

EHS patient information from the 2016 Falmouth Road Race (August, 21st, 2016) was examined (n=16; 1.54 per 1,000 runners). Seven EHS runners answered $PRE_{RACE}$ (EDU, n=2; NED, n=5), however

one record (NED, n=1) was excluded since the consent for cross examination with the medical tent data was not provided. One EHS runner in EDU two EHS runners in NED completed the $POST_{RACE.}$

*Comparison Groups*

Five of the thirty-four runners who participated in a research study at the 2016 Falmouth Road Race experienced EIH ($T_{GI}$≥40°C) with no CNS dysfunction. These runners experienced a similar magnitude of exercise-induced hyperthermia as the EHS cohort, however, did not warrant medical attention at race as they were not suffering from EHS and self-recovered back to normothermia. This cohort of runners was examined as the control to the EHS runners. Survey results from 589 runners that completed surveys at $PRE_{RACE}$ and $POST_{RACE}$ who were not admitted to medical tent for EHS were also examined (CON).

*Statistical Analysis*

All parametric variables are reported in mean ± standard deviation. Mean difference (MD) and 95% confidence interval (CI) are reported for group mean comparisons using two-tailed, sample t test. Sensitivity (SN), specificity (SP) with 95% confidence interval (CI), positive likelihood ratio (PLR; large= >10, moderate= >5 and ≤10, small= >2 and ≤5) and negative likelihood ratio (NLR; large= <0.1, moderate= ≥0.1 and <0.2, small= ≥0.2 and <0.5) were calculated for six EHS risk factors that are well established by previous literature (previous history of heat illness, activity that is novel to individual [i.e., first time running Falmouth Road Race], lack of sleep, recent illness, high motivation, and no fluid intake during exercise)[1–7] to assess their ability to distinguish EHS from EIH and EHS from CON. Statistical significance was set at $p<0.05$ a priori.

## RESULTS

### *Runner Characteristics*

Runner's sex, age, BM, maximal oxygen consumption ($VO_2max$), medication usage, and previous experience at the Falmouth Road Race are summarized in Table 3.1. Both male and female runners were represented in EHS and EIH groups. Distribution and range of age were similar between EHS and EIH groups. BM was obtained from only one EHS runner, and $VO_2max$ was only known in EIH runners who completed the $VO_2max$ as part of a larger study. Two EHS runners were on thyroid and hypercholesterolemia medication. Previous experience of Falmouth Road Race was mixed in EHS and EIH; both groups included runners who were running the race for the first time and others who were veterans completing their ≥10th race.

Average hours of sleep, history of recent illness, and previous history of heat illness obtained from $PRE_{RACE}$ and the number of hours slept the day before and the level of motivation going into the collected from $POST_{RACE}$ are summarized in Table 3.2. Recent illness was reported in two EHS (A, F) and one EIH (G) runners but none of the runners reported illness on the day before race. Previous history of heat illness was reported in two EHS runners (B, F).

### *Hydration Strategies Surrounding the Race Day*

The planned hydration strategies ($PRE_{RACE}$) and actual strategies taken on race day ($POST_{RACE}$) are summarized in Table 3.3. All runners from EHS and EIH groups reported that they took ample of water night before. Two runners in EIH (H, I) had an intention of carrying water or drinking to thirst during race but waited until after race to hydrate on race day. On the contrary, other runners (B, D, E, J, K) implemented at least one hydration strategy during race to stay hydrated.

*Knowledge on Heat Safety and Hydration*

KT scores from $PRE_{RACE}$ and $POST_{RACE}$ are summarized in Table 3.4. $PRE_{RACE}$ KT score was not different between EHS and EIH runners at $PRE_{RACE}$ (EHS, 73.3±3.3%; EIH, 70.0±5.7%; MD[95%CI]=3.3 [-11.0, 17.7]; *p*=0.612) and $POST_{RACE}$ (EHS, 78.3±9.3%; EIH, 75.0±9.4%; MD[95%CI]=3.3 [-31.4, 38.1]; *p*=0.822). All runners in EHS and EIH acknowledged that a runner may have greater risk of heat syncope if the runner is not well hydrated and recent illness and lack of sleep may predispose a runner to experience heat illness. Case C (EHS group) and Case K (EIH group) believed that exertional heat stroke can only occur in a cool environment.

*Race Data*

Goal race finish time (FT), race FT, race pace, and internal body temperature after race are summarized in Table 3.5. Only one EHS runner (Case B) and one EIH runner (Case I) were able to meet their goal time. Average FT for EHS (61.4±5.1min) was slower than EIH (56.4±1.0min) but with no statistical significance (*p*=0.405) (Table 3.5). EHS group had runners with the fastest (Case A) and slowest (Case F) finish times among the investigated individuals. There was no difference in the internal body temperature between EHS and EIH (EHS $T_{REC}$, 40.67±0.19°C; EIH $T_{GI}$, 40.38±0.18°C; MD[95%CI]=0.29 [-0.31, 0.89]; *p*=0.307) (Figure 3.1). All EHS runners were treated with cold water immersion until their $T_{REC}$ reached ≤39.0°C. The average cooling duration was 9.8±0.6min with average cooling rate of 0.18±0.01°C×min$^{-1}$ (Figure 3.2).

*Exertional Heat Stroke Risk Factors*

Observations of EHS risk factors were compared among EHS, EIH and CON (Table 3.6). The average number of risk factors per person was highest in EHS (1.88±1.47), followed by EIH (1.60±0.55)

and CON (0.75±0.78). SN, SP, PLR, and NLR for each EHS risk factor in distinguishing EHS from EIH and EHS from CON are summarized in Tables 3.7 and 3.8. High motivation demonstrated the best combination of SN and SP in distinguishing EHS from EIH and EHS from CON. None of the risk factors had PLR and NLR with practical significance when distinguishing EHS from EIH. Previous history of heat related illness was the only risk factor that demonstrated strong PLR when distinguishing EHS from CON. None of the risk factors demonstrated NLR with practical significance when distinguishing EHS from CON.

**DISCUSSION**

We examined characteristics of runners who suffered EHS using a case series comparison with runners who experienced comparable hyperthermia (EIH) from the same race. Although most of our data were contingent on runner's recollection at $POST_{RACE}$ and the accuracy of their recollection may be limited, we were able to observe that sex, age, and the number of previous Falmouth Road Race completed were non-specific to EHS or EIH runners. Two EHS runners reported that they were on thyroid and hyperlipidemia medication but influence from these drugs in increasing EHS risk is unlikely.[11] A substantial reduction in hours of sleep day before the race (E), high level of motivation (A, B, E, F), and previous history of heat illness (B, F) were unique to our EHS cohort, which is in agreement with previous observations from other case studies.[1,3] However, cases C and D did not have any of the risk factors that were examined in the study. Furthermore, KT performance and race day hydration strategy varied by individual and no apparent relationship was observed between EHS and EIH.

A wider range of finish time (47.42–84.02 minutes) was observed in EHS than EIH runners (53.78– 59.52 minutes). From the human heat balance stand point, it is not surprising for runners with faster pace to experience faster and greater rise in internal body temperautre.[12] Conversely, we also observed a runner (F) in EHS with substantially slower pace than others. The slower running pace may be

indicative of lower aerobic fitness[13], which is one of the common risk factors for EHS. Additionally, a slower runner will be exposed to environmental heat for a prolonged period of time. For example, average ambient temperature, humidity, and wet bulb globe temperature recorded at 2016 Falmouth Road Race were 25.0±1.4°C, 70.2±5.3%, and 25.8±1.1°C, which may have predisposed the runner to experience prolonged thermal strain.

The number of EHS risk factors per person was highest among EHS (1.88±1.47) followed by EIH (1.60±0.55) and CON (0.74±0.77). However, current investigation is limited to our observation of six EHS, five EIH, and 589 CON, which represented only 5% of the total registrants at the 2016 Falmouth Road Race (n=11,355). Moreover, our investigation of EIH was limited to runners who were part of a larger study. As a result, incident of post-race EIH in runners who did not require medical attention at race may be underestimated. Therefore, more years of data collection are needed to determine if there are group differences in the number of EHS risk factors observed among EHS, EIH, and CON. When each risk factor was evaluated individually, high level of motivation demonstrated the best combination of SN and SP in distinguishing EHS from EIH and distinguishing EHS from CON. Nevertheless, low SN and high SP in all EHS risk factors to distinguish EHS from EIH and EHS from CON infer that absence of any risk factors do not substantially reduce the risk of a runner suffering from EHS (i.e., low SN) and that combination of any risk factors may contribute to EHS risk profile (i.e., high SP).

## CONCLUSION

Previous case studies have characterized risk factors of EHS, however, findings from these studies were limited to the EHS patients, failing to examine the prevalence of EHS risk factors in individuals who did not experience EHS after completing the same physical activity. While previous history of heat illness, activity that is novel to the individual [i.e., first time running Falmouth Road Race], lack of sleep, high motivation, and absence of fluid intake during race were observed in runners

who were treated for EHS at the 2016 Falmouth Road Race, these risk factors were not exclusive to EHS and similar characteristics were observed in EIH and CON runners. While the current study found that reported number of risk factors per runner was highest in EHS, more EHS cases are needed to determine if greater number of risk factors is a unique characteristic among EHS runners.

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**Figure Legends:**

Figure 3.1. Comparison of post race internal body temperature in exertional heat stroke runners (EHS, 40.67±0.19°C) and exercise-induced hyperthermia runners (EIH, 40.38±0.18°C) (p=0.307). Internal body temperature for EHS and EIH were measured using rectal thermometer and gastrointestinal pill, respectively.

Figure 3.2. The duration and rate of cooling observed in exertional heat stroke runners during their treatment using cold water immersion. All runners were cooled until their rectal temperature reached ≤39.0°C (gray line).

Figure 3.1.

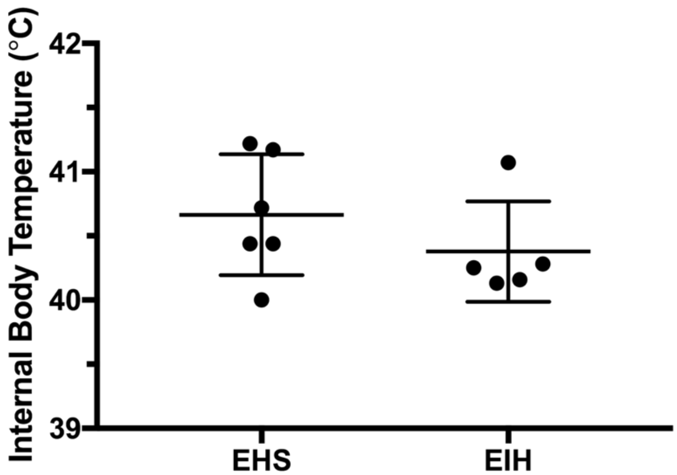


Figure 3.2.

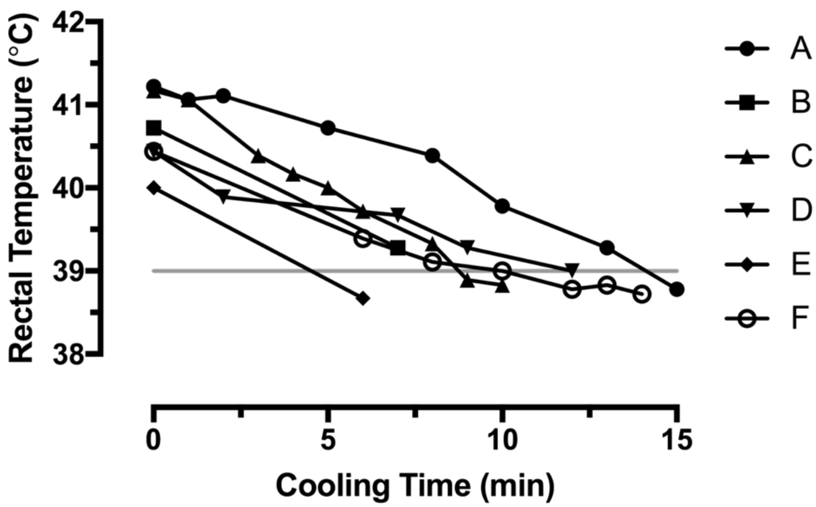

Table 3.1

**Table 3.1. Runner Characteristics A**

| Case | Sex | Age (years) | Body Mass (kg) | $VO_2$ max ($ml\cdot kg^{-1}\cdot min^{-1}$) | Medication | Number of Previous FRR |
|---|---|---|---|---|---|---|
| *Exertional Heat Stroke Group* | | | | | | |
| A | Female | 27 | - | - | None | 0 |
| B | Male | 59 | - | - | Levothyroxin, Statin | 9 |
| C | Female | 31 | 83.9 | - | Thyroidine, Statins | 9 |
| D | Male | 36 | - | - | None | 3 |
| E | Male | 42 | - | - | None | 0 |
| F | Female | 24 | - | - | None | 4 |
| *Exercise-Induced Hyperthermia Group* | | | | | | |
| Case | Sex | Age (years) | Body Mass (kg) | $VO_2$ max ($ml\cdot kg^{-1}\cdot min^{-1}$) | Medication | Number of Previous FRR |
| G | Male | 23 | 76.5 | 45.40 | None | 0 |
| H | Female | 38 | 65.0 | 47.70 | None | 3 |
| I | Female | 50 | 57.8 | 40.60 | None | 3 |
| J | Male | 59 | 67.3 | 46.97 | None | 10 |
| K | Female | 46 | 69.3 | 38.75 | None | 2 |

$VO_2$ max= maximal oxygen consumption , FRR= Falmouth Road Race

Table 3.2

**Table 3.2. Runner Characteristics B**

| Case | Average Sleep (hours) | Sleep Day Before Race (hours) | Motivation (5/5) | Illness 7 Days Before Race | Illness Day Before Race | Previous History of Heat Illness |
|---|---|---|---|---|---|---|
| *Exertional Heat Stroke Group* | | | | | | |
| A | 7 | - | 5 | Yes | No | None |
| B | 5 | 5 | 5 | No | No | Heat exhaustion |
| C | 7 | - | 4 | No | No | None |
| D | 6 | 6 | 4 | No | No | None |
| E | 7 | 4 | 5 | No | No | None |
| F | 7 | - | 5 | Yes | No | Exertional heat stroke |
| *Exercise-Induced Hyperthermia Group* | | | | | | |
| Case | Average Sleep (hours) | Sleep Day Before Race (hours) | Motivation (5/5) | Illness 7 Days Before Race | Illness Day Before Race | Previous History of Heat Illness |
| G | 6 | 7 | 4 | Yes | No | None |
| H | 7 | 7 | 3 | No | No | None |
| I | 6 | 5 | 4 | No | No | None |
| J | 6 | 7 | 3 | No | No | None |
| K | 8 | 6 | 4 | No | No | None |

Table 3.3

**Table 3.3. Hydration Strategy Intention and Race Day Behavior**

| Case | Avoid Alcohol Night Before | | Drink Ample of Water Night Before | | Carry Water | | Stop at Some Water Stations | | Stop at All Water Stations | | Drink to Thirst | | Wait Until After Race | | Avoid Caffeine | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Exertional Heat Stroke Group* | | | | | | | | | | | | | | | | |
| | INT | BHV | INT | BHV | INT | BHV | INT | BHV | INT | BHV | INT | BHV | INT | BHV | INT | BHV |
| A | Yes | - | Yes | - | No | - | Yes | - | Yes | - | No | - | No | - | No | - |
| B | Yes | Yes | Yes | Yes | No | No | No | No | Yes | Yes | No | No | No | No | No | Yes |
| C | Yes | - | Yes | - | No | - | No | - | No | - | Yes | - | No | - | No | - |
| D | Yes | Yes | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes | No | No | No | No | No | No |
| E | No | No | Yes | Yes | No | No | Yes | Yes | No | No | Yes | No | No | Yes | No | No |
| F | Yes | - | Yes | - | No | - | Yes | - | Yes | - | Yes | - | No | - | Yes | - |
| *Exercise-Induced Hyperthermia Group* | | | | | | | | | | | | | | | | |
| Case | Avoid Alcohol Night Before | | Drink Ample of Water Night Before | | Carry Water | | Stop at Some Water Stations | | Stop at All Water Stations | | Drink to Thirst | | Wait Until After Race | | Avoid Caffeine | |
| | INT | BHV | INT | BHV | INT | BHV | INT | BHV | INT | BHV | INT | BHV | INT | BHV | INT | BHV |
| G | Yes | No | Yes | Yes | Yes | No | No | No | No | No | No | No | Yes | No | No | No |
| H | Yes | Yes | Yes | Yes | Yes | No | Yes | No | No | No | Yes | No | No | Yes | No | No |
| I | Yes | Yes | Yes | Yes | Yes | No | No | No | No | No | Yes | No | No | Yes | No | No |
| J | Yes | Yes | Yes | Yes | Yes | No | No | Yes | Yes | No | No | Yes | No | No | No | No |
| K | Yes | Yes | Yes | Yes | Yes | No | Yes | Yes | No | No | No | No | No | No | No | No |

INT= intention, BHV= behavior

Table 3.4

**Table 3.4. Knowledge Test Score (%)**

| Case | Survey Group | Pre Race | Post Race |
|---|---|---|---|
| *Exertional Heat Stroke Group* | | | |
| A | EDU | 65 | - |
| B | EDU | 80 | 90 |
| C | NED | 70 | 85 |
| D | NED | 75 | 60 |
| E | NED | 65 | - |
| F | NED | 85 | - |
| *Exercise-Induced Hyperthermia Group* | | | |
| Case | Survey Group | Pre Race | Post Race |
| G | EDU | 60 | 50 |
| H | EDU | 60 | 95 |
| I | EDU | 90 | 85 |
| J | EDU | 75 | 90 |
| K | EDU | 65 | 55 |

EDU= educational video intervention group, NED= control group

Table 3.5

**Table 3.5. Race Data**

| Case | Goal Finish Time | Finish Time | Pace (km·min$^{-1}$) | $T_{REC}$ (°C) |
|---|---|---|---|---|
| *Exertional Heat Stroke Group* | | | | |
| A | - | 0:47:25 | 0:04:19 | 41.22 |
| B | < 0:60:00 | 0:59:33 | 0:05:25 | 40.72 |
| C | 0:50:00 | 0:53:10 | 0:04:50 | 41.17 |
| D | < 0:60:00 | 1:02:36 | 0:05:41 | 40.44 |
| E | < 0:60:00 | 1:01:37 | 0:05:36 | 40.00 |
| F | 0:58:00 | 1:24:01 | 0:07:38 | 40.44 |
| *Exercise-Induced Hyperthermia Group* | | | | |
| Case | Goal Finish Time | Finish Time | Pace (km·min$^{-1}$) | $T_{GI}$ (°C) |
| G | 0:49:00 | 0:54:47 | 0:04:59 | 40.16 |
| H | 0:56:00 | 0:57:43 | 0:05:15 | 41.07 |
| I | 0:56:30 | 0:56:14 | 0:05:07 | 40.13 |
| J | 0:52:30 | 0:53:47 | 0:04:53 | 40.25 |
| K | 0:49:00 | 0:59:31 | 0:05:25 | 40.28 |

Time= (h:mm:ss), $T_{REC}$ = rectal temperature, $T_{GI}$ = gastrointestinal temperature

Table 3.6

**Table 3.6. Number of Risk Factor Observations**

| Risk Factor | EHS *n*=6 | EIH *n*=5 | CON *n*=589 |
|---|---|---|---|
| 1. Previous history of heat related illness | 2 | 0 | 10 |
| 2. First time running FRR | 2 | 4 | 207 |
| 3. Lack of sleep ( ≥3 hours less than usual) | 1 | 0 | 30 |
| 4. Recent illness 7 days before race | 2 | 2 | 43 |
| 5. High motivation (5/5) | 4 | 0 | 111 |
| 6. No fluid intake during race | 0 | 2 | 35 |
| 7. Average number of risk factors per person (1-6) | 1.88±1.47 | 1.60±0.55 | 0.74±0.77 |

FRR= Falmouth Road Race, EHS= exertional heat stroke group, EIH= exericise-induced hyperthermia group, CON= all survey respondents excluding EHS

Table 3.7

**Table 3.7. Predictive Accuracy of EHS Risk Factor in Distinguishing EHS from EIH**

| Risk Factor | SN | 95% CI | SP | 95% CI | PLR | NLR |
|---|---|---|---|---|---|---|
| 1. Previous history of heat related illness | 33% | 4.3-77.7% | 100% | 47.8-100% | - | 0.7 |
| 2. First time running FRR | 33% | 4.3-77.7% | 20% | 0.5-71.6% | 0.4 | 3.3 |
| 3. Lack of sleep ( ≥3 hours less than usual) | 17% | 0.4-64.1% | 100% | 47.8-100% | - | 0.8 |
| 4. Recent illness 7 days before race | 33% | 4.3-77.7% | 60% | 14.7-94.7% | 0.8 | 1.1 |
| 5. High motivation (5/5) | 67% | 22.3-95.7% | 100% | 47.8-100% | - | 0.3 |
| 6. No fluid intake during race | - | - | 60% | 14.7-94.7% | 0.0 | 1.7 |

FRR= Falmouth Road Race, EHS= exertional heat stroke group, EIH= exericise-induced hyperthermia group, SN= sensitivity, SP= specificity, PLR= positive likelihood ratio, NLR= negative likelihood ratio, CI= confidence interval

Table 3.8

**Table 3.8. Predictive Accuracy of EHS Risk Factor in Distinguishing EHS from CON**

| Risk Factor | SN | 95% CI | SP | 95% CI | PLR | NLR |
|---|---|---|---|---|---|---|
| 1. Previous history of heat related illness | 33% | 4.3-77.7% | 98% | 96.9-99.2% | 19.6 | 0.7 |
| 2. First time running FRR | 33% | 4.3-77.7% | 65% | 60.9-68.7% | 0.9 | 1.0 |
| 3. Lack of sleep ( ≥3 hours less than usual) | 17% | 0.4-64.1% | 95% | 92.8-96.5% | 3.3 | 0.9 |
| 4. Recent illness 7 days before race | 33% | 4.3-77.7% | 93% | 90.3-94.7% | 4.6 | 0.7 |
| 5. High motivation (5/5) | 67% | 22.3-95.7% | 81% | 77.8-84.2% | 3.5 | 0.4 |
| 6. No fluid intake during race | - | - | 94% | 91.8-95.8% | - | - |

FRR= Falmouth Road Race, EHS= exertional heat stroke group, CON= all survey respondents excluding EHS, SN= sensitivity, SP= specificity, PLR= positive likelihood ratio, NLR= negative likelihood ratio, CI= confidence interval

**Appendix I. Survey questions sent at pre race, post education, and post race**

**Section I: History and Behavior Questionnaire for Pre Race**

1. Have you been diagnosed with any of the following conditions by a licensed healthcare professional in the last three years? [Select all that apply]
   - ☐ Heat syncope (i.e., passing out)
   - ☐ Heat exhaustion
   - ☐ Exertional heat stroke (i.e., during or after physical activity)
   - ☐ Classic heat stroke (i.e., non-physical activity related)
   - ☐ Rhabdomyolysis
   - ☐ None
2. On average, I sleep [_____] hours per night.
   - ☐ ≤3
   - ☐ 4
   - ☐ 5
   - ☐ 6
   - ☐ 7
   - ☐ 8
   - ☐ 9
   - ☐ 10
   - ☐ ≥11
3. I sleep in an air-conditioned room when it is hot.
   - ☐ Always
   - ☐ Most of the time
   - ☐ About half the time
   - ☐ Sometimes
   - ☐ Never
4. For my day-time job, I work in an air-conditioned environment.
   - ☐ Yes
   - ☐ Mostly
   - ☐ Half of the time
   - ☐ Mostly no
   - ☐ No
5. I am highly motivated to achieve my personal best and/or to run faster than other race participant(s) at this year's race.
   - ☐ Strongly agree
   - ☐ Somewhat agree
   - ☐ Neither agree nor disagree
   - ☐ Somewhat disagree
   - ☐ Strongly disagree
6. I was sick in the last 7 days.
   - ☐ Yes
   - ☐ No
7. I know my sweat rate.
   - ☐ Yes
   - ☐ No
8. I have been training for: [Select all that apply]
   - ☐ 2016 Falmouth Road Race
   - ☐ Half marathon
   - ☐ Full marathon

☐ Ultra marathon or any race longer than full marathon
☐ Other
*If yes:* Please specify in the text box below. [Open ended question]

9. I plan on taking medication(s) or supplement(s) on the race day.
   ☐ Yes
   ☐ No
   *If yes:* Please specify what medication(s) or supplement(s) you plan on taking in the text box below. [Open ended question]

10. To optimize hydration, I plan to: [Select all that apply]
   ☐ Avoid alcohol the night before
   ☐ Drink ample amount of water the night before
   ☐ Carry my own water bottle/pouch
   ☐ Take a drink at water station(s) along the course
   ☐ Take a drink at all water stations along the course
   ☐ Drink when I am thirsty
   ☐ Wait until after the race to rehydrate
   ☐ Avoid caffeinated beverages
   ☐ Other: Please specify in the text box below. [Open ended question]

**Section II: Knowledge Test for Pre Race, Post Education, and Post Race**

1. Drinking an ample amount of water the night before will help ensure that you are well-hydrated next morning.
   ☐ True
   ☐ False
2. You should always stop at every water station on the race course to maintain your hydration level.
   ☐ True
   ☐ False
3. The following methods are reliable in knowing that you are dehydrated EXCEPT:
   ☐ Dark urine color
   ☐ Thirst
   ☐ Increase in body weight
   ☐ All choices are correct
4. A runner may be susceptible to heat syncope (i.e., passing out) if the runner is not well hydrated.
   ☐ True
   ☐ False
5. A runner may be susceptible to heat syncope (i.e., passing out) if the runner wears compression sportswear.
   ☐ True
   ☐ False
6. Heat exhaustion is the inability to control sweating in the heat.
   ☐ True
   ☐ False
7. [_____] can be life-threatening if not treated properly.
   ☐ Exertional heat stroke
   ☐ Heat exhaustion
   ☐ Heat syncope
   ☐ All choices are correct

8. Exertional heat stroke is more common in [_____] conditions.
   - ☐ Hot and humid
   - ☐ Hot and dry
9. For the body to adapt to exercising in the heat, the body needs at least [_____] of consecutive heat exposure.
   - ☐ 3 days
   - ☐ 7-14 days
   - ☐ 14-28 days
   - ☐ At least a month
10. As your body adapts to exercising in the heat you will sweat:
    - ☐ Less
    - ☐ More
11. In order to optimize performance in the heat, you should know your sweat rate.
    - ☐ True
    - ☐ False
12. Lack of sleep is one of the predisposing factors for exertional heat stroke.
    - ☐ True
    - ☐ False
13. Exertional heat stroke only occurs when the outdoor temperature is above 90 degrees Fahrenheit.
    - ☐ True
    - ☐ False
14. Heat exhaustion has similar cause as fever.
    - ☐ True
    - ☐ False
15. During exercise, you can never drink too much water.
    - ☐ True
    - ☐ False
16. You know you are well hydrated when your urine color is light yellow.
    - ☐ True
    - ☐ False
17. Exertional heat stroke can occur in a cool environment.
    - ☐ True
    - ☐ False
18. Recent illness may predispose you to experience heat illness.
    - ☐ True
    - ☐ False
19. You must be severely dehydrated to experience exertional heat stroke.
    - ☐ True
    - ☐ False
20. The defining body temperature for exertional heat stroke is:
    - ☐ 101.5
    - ☐ 102.5
    - ☐ 103.5
    - ☐ 104.5

**Section III: Demographics for Pre Race**

1. Are you currently taking part in the research study by the Korey Stringer Institute? *or* Have you been part of the research study by the Korey Stringer Institute in the past?
   - ☐ Yes, for the 2016 Falmouth Road Race

- ☐ Yes, in the previous Falmouth Road Race(s)
- ☐ No

2. How many times have you participated in the Falmouth Road Race?
   - ☐ This is my first time
   - ☐ 1
   - ☐ 2
   - ☐ 3
   - ☐ 4
   - ☐ 5
   - ☐ 6
   - ☐ 7
   - ☐ 8
   - ☐ 9
   - ☐ 10 or more
3. I classify my sex as:
   - ☐ Male
   - ☐ Female
   - ☐ Other: Please specify in the text box below.
   - ☐ Prefer not to answer
4. Age group
   - ☐ Under 20
   - ☐ 20-29
   - ☐ 30-39
   - ☐ 40-49
   - ☐ 50-59
   - ☐ 60-69
   - ☐ 70-79
   - ☐ 80 or older
5. Are you a licensed healthcare professional?
   - ☐ Yes
   - ☐ No

   *If yes:* Please choose your medical training background from the following list:

   - ☐ Athletic Training
   - ☐ Anesthesiology
   - ☐ Chiropractic
   - ☐ Emergency Medicine
   - ☐ General Medicine
   - ☐ Occupational Therapy
   - ☐ Paramedics
   - ☐ Pediatrics
   - ☐ Pharmacology
   - ☐ Physical Therapy
   - ☐ Sports Medicine
   - ☐ Other: Please explain your medical training background in the text box below.
6. By providing your initials below, you agree that:

*In the event of medical tent admittance at the Falmouth Road Race, I give my permission for the medical staff at the Falmouth Road Race to share my personal medical information obtained at the medical tent with University of Connecticut for research purpose only.*

**Section IV: History and Behavior Questionnaire for Post Race**

1. Did you seek medical attention at the medical tent?
   - ☐ No
   - ☐ Yes; heat syncope (i.e., passing out)
   - ☐ Yes; heat exhaustion
   - ☐ Yes; exertional heat stroke
   - ☐ Yes; abrasion
   - ☐ Yes; muscle pain/ injury
   - ☐ Yes; joint pain/ injury
   - ☐ Yes; other
2. I slept [_____] hours the night before the race.
   - ☐ ≤3
   - ☐ 4
   - ☐ 5
   - ☐ 6
   - ☐ 7
   - ☐ 8
   - ☐ 9
   - ☐ 10
   - ☐ ≥11
3. I slept in an air-conditioned room the night before the race.
   - ☐ Yes
   - ☐ No
4. I was highly motivated to achieve my personal best and/or to run faster than other race participant(s) at this year's race.
   - ☐ Strongly agree
   - ☐ Somewhat agree
   - ☐ Neither agree nor disagree
   - ☐ Somewhat disagree
   - ☐ Strongly disagree
5. I felt I trained adequately for the race.
   - ☐ Strongly agree
   - ☐ Somewhat agree
   - ☐ Neither agree nor disagree
   - ☐ Somewhat disagree
   - ☐ Strongly disagree
6. I was sick the day before the race.
   - ☐ Yes
   - ☐ No
7. I knew my sweat rate rate going in to the race.
   - ☐ Yes
   - ☐ No
8. I took medication(s) or supplement(s) in the morning of the race.
   - ☐ Yes
   - ☐ No

   *If yes:* Please specify what medication(s) or supplement(s) you plan on taking in the text box below. [Open ended question]

9. For hydration, I: [Select all that apply]
   - ☐ Avoided alcohol the night before

- ☐ Had ample amount of water the night before
- ☐ Carried my own water bottle/pouch
- ☐ Took a drink at water station(s) along the course
- ☐ Took a drink at all water stations along the course
- ☐ Drank when I am thirsty
- ☐ Waited until after the race to rehydrate
- ☐ Avoided caffeinated beverages
- ☐ Other: Please specify in the text box below. [Open ended question]

**Section V: Demographics for Post Race**

1. Are you currently taking part in the research study by the Korey Stringer Institute? *or* Have you been part of the research study by the Korey Stringer Institute in the past?
   - ☐ Yes, for the 2016 Falmouth Road Race
   - ☐ Yes, in the previous Falmouth Road Race(s)
   - ☐ No
2. How many times have you participated in the Falmouth Road Race?
   - ☐ This is my first time
   - ☐ 1
   - ☐ 2
   - ☐ 3
   - ☐ 4
   - ☐ 5
   - ☐ 6
   - ☐ 7
   - ☐ 8
   - ☐ 9
   - ☐ 10 or more
3. I classify my sex as:
   - ☐ Male
   - ☐ Female
   - ☐ Other: Please specify in the text box below.
   - ☐ Prefer not to answer
4. Age group
   - ☐ Under 20
   - ☐ 20-29
   - ☐ 30-39
   - ☐ 40-49
   - ☐ 50-59
   - ☐ 60-69
   - ☐ 70-79
   - ☐ 80 or older
5. Are you a licensed healthcare professional?
   - ☐ Yes
   - ☐ No

   *If yes:* Please choose your medical training background from the following list:

   - ☐ Athletic Training
   - ☐ Anesthesiology
   - ☐ Chiropractic
   - ☐ Emergency Medicine

- ☐ General Medicine
- ☐ Occupational Therapy
- ☐ Paramedics
- ☐ Pediatrics
- ☐ Pharmacology
- ☐ Physical Therapy
- ☐ Sports Medicine
- ☐ Other: Please explain your medical training background in the text box below.

6. Did you watch the heat and hydration video created by the Korey Stringer Institute before the race?
   - ☐ Yes
   - ☐ No

**Appendix II. Educational video script with annotations on corresponding knowledge test questions**

Video script:
This video will go over ways to optimize exercise performance in the heat and prevent heat illness.

Exercising in the heat poses a unique stress on the body. For example, when you are running outdoors, direct sunlight, high air temperature, or high humidity will add additional heat strain on the body in addition to what is already being produced from the working muscles.

In order to combat the rise in body temperature, the body begins to sweat to remove body heat by evaporation of the sweat from the skin. In fact, sweating is the predominant method of dissipating body heat during exercising in the heat.

When the body is not used to exercising in hot conditions, its ability to dissipate heat is not as efficient. However, through gradual exposure to the heat and exercising in the heat, the body will undergo a series of adaptations to cope with heat stress during exercise to optimize body temperature control. This process is called heat acclimatization. It usually takes between 10-14 days to gain the favorable adaptations, which include: increased sweat rate, increased exercise capacity, decreased heart rate, decreased rate of rise in internal body temperature, and decreased sodium loss in the sweat.[KT9, 10]

Hydration is another component that plays a crucial role in maintaining body temperature stability while exercising in the heat, as well as an optimizing performance. It is important to start exercising in a well-hydrated state, minimize fluid losses during exercise, and replenish the remaining fluid deficit after exercise. A quick way to check your hydration status is by simply looking at your urine color. If the urine color is light yellow, resembling the color of lemonade, it indicates that you are hydrated.[KT16] On the other hand, if your urine color is dark like the color of apple juice, you are likely to be dehydrated.[KT3] If you are scheduled to exercise in the morning, drinking an ample amount of water the night before will help you start out the exercise in the well-hydrated state.[KT1] Thirst is another way of your body alarming that you are dehydrated, too.[KT3]

The amount of water you drink during and after exercise should be tailored to your individual needs. This can be accomplished by measuring your body weight before and after exercise to calculate the difference between the two measurements.[KT3] Calculating your own sweat rate will provide an individualized hydration regimen that will not only help you prevent significant dehydration but also help you to prevent over-drinking or in a severe case, water intoxication.[KT11, 15] Depending on your sweat rate, stopping at every water station may not be necessary.[KT2]

In addition to heat acclimatization and hydration, it is also important to know your general health status and fitness level. To further optimize your exercise performance in the heat you should get quality sleep, avoid sleeping in a non-air-conditioned room during heat wave, and choose an exercise intensity that is best matched to your fitness level.[KT12, 19]

All factors mentioned thus far will also work in your favor to prevent heat illnesses. Heat illnesses are often seen with increased body temperature. It should be noted that the underlining mechanism of increased body temperature is different from fever.[KT14] Heat syncope refers to a fainting or lightheadedness episode during or immediately after exercise. It is caused by lack of blood returning to the heart, and is commonly seen in people who are not used to the heat or are dehydrated.[KT4, 5] When an exercising individual can no longer continue activity in the heat due to fatigue, this is called heat exhaustion.[KT6] Although heat exhaustion is not a life threatening condition, it is important to rehydrate and cool the body down using methods such as water immersion, cold towels, or moving to a cool area. The most severe form of heat illness is called exertional heat stroke. Exertional heat stroke is a life-

threatening condition if not recognized and treated appropriately.[KT7] It is diagnosed when the patient's rectal temperature is over 104.5°F with signs of central nervous system dysfunction.[KT20] The risk increases when the environment is hot and humid but it can also happen in cool environment.[KT8, 13, 17] The key for exertional heat stroke treatment is to reduce the body temperature within the safe range within 30 minutes of collapse.

Taken together, exercise in the heat adds unique challenges to the body but it can be reduced with heat acclimatization, proper hydration, quality sleep, and knowing the exercise intensity that bests fits your fitness level. If you were recently ill, or do not feel ready to participate in exercise, it is always important to listen to your body and perhaps postpone the activity until you feel ready again.[KT18]

Thank you for watching our video. This has been the Korey Stringer Institute. We hope you have a good run.

Memorandum:
KT[#], corresponding knowledge test question number on the survey.
Video duration, 04:43.

**Appendix III. List of medications and supplements reported by 2016 Falmouth Road Race runners**

| Drug Category | | Special Considerations | PRE EDU | PRE NED | POST EDU | POST NED |
|---|---|---|---|---|---|---|
| Analgesic | | | 4 | 5 | 2 | 5 |
| Anti-inflammatory | Steroids | | 3 | 5 | 1 | 4 |
| | NSAID | | 28 | 38 | 10 | 34 |
| Antibiotic | | | 3 | 2 | 0 | 1 |
| Anticoagulant | | | 4 | 7 | 0 | 1 |
| Anticholinergic | | Decreased sweat production | 0 | 1 | 0 | 0 |
| Anticonvulsant | | | 3 | 3 | 0 | 2 |
| Anti-diabetic | | | 4 | 2 | 1 | 0 |
| Antihistamine | | Decreased sweat production | 18 | 10 | 7 | 15 |
| Anxiolytic | | | 3 | 0 | 1 | 1 |
| Aspirin | | Increase heat production | 8 | 11 | 2 | 6 |
| Asthma | | | 13 | 29 | 2 | 11 |
| Cardiac | Beta blocker | Decrease cardiac contractility | 8 | 8 | 1 | 2 |
| | Calcium channel blocker | Alter skin blood flow<br>Decrease cardiac contractility | 0 | 4 | 0 | 1 |
| | Anti-arrhythmic | | 2 | 1 | 0 | 1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Anti-hypertensive | | 18 | 21 | 5 | 11 |
| Cholesterol | | | 8 | 16 | 0 | 4 |
| Expectorant | | | 2 | 0 | 1 | 0 |
| Gastrointestinal | | | 4 | 7 | 2 | 8 |
| Glaucoma | | | 2 | 1 | 0 | 0 |
| Hormone | Inhibitor | | 2 | 2 | 0 | 2 |
| | Contraception | Alter skin blood flow | 5 | 16 | 0 | 11 |
| | Thyroid | | 19 | 16 | 6 | 11 |
| | Other | | 0 | 3 | 0 | 2 |
| Immunosuppressant | | | 2 | 2 | 0 | 0 |
| Selective serotonin reuptake inhibitor | | Serotonin syndrome | 16 | 21 | 6 | 11 |
| Stimulant | | Increase heat production | 6 | 4 | 4 | 3 |
| Supplement | Vitamin | | 52 | 54 | 14 | 29 |
| | Caffeine | | 4 | 2 | 1 | 1 |
| | Carbohydrate | | 20 | 22 | 1 | 17 |
| | Workout | | 11 | 9 | 1 | 6 |
| | Electrolyte | | 23 | 21 | 4 | 11 |
| | Other | | 58 | 52 | 11 | 24 |

| | | | | |
|---|---|---|---|---|
| Other | 5 | 4 | 7 | 4 |

Abbreviations: EDU, educational video intervention group; NED, control group; NSAID, non-steroidal anti-inflammatory drugs; PRE, pre race survey; POST, post race survey.