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An Investigation of the Factors Associated with Gastrointestinal Temperature of Cyclists During the 2017 Hotter 'N Hell Hundred 164-km Cycling Event

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Master of Science Thesis

An Investigation of the Factors Associated with Gastrointestinal Temperature of Cyclists During the 2017 Hotter 'N Hell Hundred 164-km Cycling Event

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About five years ago, I started learning about movement, hydration, and nutrition, so I decided to build on my new hobby and pursue a formal education from one of the top programs in the country – the UConn Department of Kinesiology. As a cell biologist, I was ready for the challenge of learning a different way to explore science research. I knew I would not feel satisfied just taking classes because I truly missed being a part of a research project. *This* cognitive challenge was precisely what I was seeking. The courses I enrolled in have been fascinating and generated so much discussion, and Thermal was the toughest course I can ever remember taking.

My mission while pursuing this degree was to not sacrifice other parts of my life – strength and conditioning training, cooking, visiting friends and family, and leading the UConn McNair Scholars Program. I ran my 20th 5-km run for my 35th birthday, have trained and tapered to compete in two powerlifting meets and the third meet is set for this summer, and UConn McNair has earned five more years of funding from the U.S. Department of Education. Mission accomplished.

I am truly grateful to Drs. Craig Denegar and Lawrence Armstrong for meeting with me to discuss the feasibility of pursuing this degree while leading the UConn McNair Scholars Program year-round. To Dr. Elaine Lee, I have seen first-hand how four McNair Scholars have matured into inquisitive researchers because of their time with you, and am thankful to grow from your expertise as well. To Dr. Rob Huggins, if you had not accepted the invite to present your research in the Fall of 2015, I would not have realized how much I really wanted to do this.

I decided that day to seriously consider applying for this graduate program. To Dr. Armstrong, I have tremendously enjoyed learning from you as a professor in three of the four lecture courses I have taken, and all of the brainstorm sessions on the whiteboard to advance my thesis project. Traveling to Wichita Falls, TX to be immersed in a full, field research experience was incredible. I have tried my best to make you proud as your final graduate student. Moreover, I thank you for mentoring two McNair Scholars to help them realize their academic and professional potential.

To my Ph.D. advisor, Dr. David Knecht, because I grew so much from having an advisor who consistently pushed me to new limits, I was inspired to achieve that again. I can think of two of my students who are also quite fortunate you are still on campus, to have you as a professional and personal mentor like I do. To my colleagues in the UConn Center for Academic Programs, thank you for your support as I try to lead by example for our students, who have been enthusiastic cheerleaders of my pursuit. To my coach, Trevor Brunelle, for keeping me balanced and in great health, helping me continue to gain strength and confidence, listening, and reminding me when to prioritize my studies over training, I could not have conquered all I have with any other coach. To my family for whom I never do anything "by halves" and my friends with whom I celebrate great, life achievements, I am not sure this will be my final graduate degree, but I do promise to apply my knowledge to rewarding opportunities in the future, like outreach with youth and perhaps a teaching position!

It has been really fun doing this for myself, heart and soul, but certainly could not do this by myself.

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ABSTRACT

Non-elite cyclists are the typical participants of the Hotter 'N Hell (HHH) 164-km event each August in Wichita Falls, TX. The goal of this study was to elucidate which anthropometric, physiological, and performance factors are associated with change in gastrointestinal temperature (T_{GI}) of non-elite cyclists during (Aim 1) and one hour after (Aim 2) the event. Forty-three (41 male, 2 female) participants (mean±SD; age, 51±11y; body mass (BM), 87±12.1kg; height, 1.76±0.06m; BMI, 28±3.3 $kg \cdot m^{-2}$) ingested a thermistor pill the evening before the event (DAY-1) for T_{GI} detection in the morning (PRE), at the 97-km mark (MID), at the finish (POST), and one hour post-event (REC) at the finish line. The average environmental conditions were 25.5°C (30°C maximum), 75%rh (93% maximum), and 6mph wind speed (14mph maximum). *Aim 1:* There were statistically significant increases ($p < 0.01$) in T_{GI}, the perception of thirst and thermal sensations, RPE, as well as BM over time. When comparing PRE with POST, only perception of thirst and thermal sensations correlated with T_{GI} ($p < 0.001$). When comparing MID with POST, RPE correlated with T_{GI} ($p < 0.05$). None of the factors studied, aside from age, were significantly associated with POST T_{GI}. *Aim 2:* POST to REC ($n = 37$) T_{GI} and perception of thermal sensation measurements significantly decreased ($p < 0.01$) over time. When comparing POST with REC, only the perception of thermal sensation correlated with T_{GI} ($p < 0.001$). T_{GI} was associated with change in perception of thirst (21%, $p = 0.04$) and thermal (14%, $p = 0.023$) sensations. Across all time points (PRE through REC), the perception of thirst and thermal sensations ($p < 0.001$), and RPE and age ($p<0.005$) correlated with T_{GI}. In sum, during a 164-km cycling event in a warm environment, T_{GI} was minimally associated with perception of thirst and thermal sensation, indicating that only mild physiological strain occurred.

CHAPTER 1: LITERATURE REVIEW

This review of the literature provides an overview of endurance exercise as well as the effects of exercising in the heat, at the physiological and cellular levels. This review will also detail the roles that dehydration, acclimatization, and the environment play in performance. Using T_{GI} as the tool for assessing internal body temperature and the risk of heat illnesses will also be described, as well as gaps in the literature to demonstrate the importance of this research study.

The physiology of endurance athletes

Endurance athletes can typically be characterized by their high gross efficiency (GE), peak oxygen uptake (VO_{2peak}), VO_{2max}, ability to maintain peak power output, pacing strategy (Atkinson et al., 2007; Schmit et al., 2016), and great blood lactate levels (Bell et al., 2016). Well-trained endurance cyclists, for instance, have a GE between 10 and 25% (Gaesser and Brooks, 1975); the GE of professional cyclists can increase up to 28.1% (Lucia et al., 2002; Santalla et al., 2012). Elite cross-country skiers exhibit very high VO_{2max}, exercise ventilation rates, cardiac outputs, and stroke volumes (Holmberg et al., 2007; Holmberg, 2015; Sandbakk et al., 2016; Tønnessen et al., 2015); they may endeavor to elevate their VO_{2peak} to more than 95% of their VO_{2max} even though they have little muscle mass, which is a unique trait of cross-country skiers (Holmberg, 2015). GE is inversely related to VO_{2peak}, thus a high GE may compensate for low VO_{2peak} (Lucia et al., 2002). Peak power output and blood lactate levels are related and are predictive of maximal efforts that endurance athletes are able to maintain (Padilla et al., 2000).

Although there are similarities among endurance athletes, there are also differences. Cyclists differ from distance runners, for instance, because they are able to carry their water with them on their bike and drink to thirst, whereas runners wait for water stops, and the same for triathletes, aside from the cycling portion. Furthermore, runners can experience gastrointestinal distress and bleeding due to a reduction in blood flow to the gut because of the mechanical impact of the sport (Brouns and Beckers, 1993; Moses, 1990), which is absent when cycling (Adams et al., 2018). A study performed on triathletes, cyclists, and marathon runners by Hoogsteen et al. (2004) demonstrates that there are significantly different adaptations of the left ventricle of the heart.

Cyclists can also utilize the wind to thermoregulate; air flow aids convective and evaporative heat loss, reduces cardiovascular drift, and improves exercise tolerance (Morrison et al., 2014). This is one reason why exertional heat stroke is rare among cyclists; it is more common among runners (Hosokawa, 2016; Rae et al., 2008), but is still quite rare. Furthermore, the main reason there is an increased likelihood of exertional heat illness and heat stroke in running is because the pace is faster, which yields greater metabolic heat production compared to marathon (and endurance cycling) distances, where the pacing strategy is slower (DeMartini et al., 2014).

Endurance training in the heat

<u>Thermoregulation</u>

It is essential for the body to maintain its temperature at 37° Celsius for proper function. Change in heat storage (S) yields a change in body temperature; when more heat is produced than dissipated, the temperature rises (positive heat storage) and, if the body produces less heat than what is lost to the environment, the temperature falls (negative heat storage) (Santee and Gonzalez, 1988). Body heat is generated from the environment and is metabolically produced in order to maintain (to thermoregulate) the set point temperature at 37°C (Castellani, 2003; Knochel and Reed, 1994). If the preoptic area of the anterior hypothalamus (PO/AH) temperature increases above the set point temperature, peripheral and hypothalamic heat receptors activate warm-sensitive neurons for heat loss to occur via a heat exchange pathway (evaporation (E), radiation (R), conduction (C), convection (K)) (Gagge and Gonzalez, 1996), and if the PO/AH temperature is below the set point, then cold-sensitive neurons increase their firing rate for heat gain to occur (Boulant, 1997). If the air surrounding the body is not saturated with water, sweat vaporizes to cool the body (Adams et al., 1975). The following heat balance equation demonstrates the relationship between metabolic heat production (M) and loss: $S = M - (\pm \text{Work}) \pm E \pm R \pm C \pm K$. Positive values refer to heat gain and negative values refer to heat loss (Gagge and Gonzalez, 1996).

Dehydration

Dehydration-induced hypovolemia increases heart rate in order to maintain cardiac output (Gonzalez-Alonso et al., 1997) and decreases blood flow and sweat rate, which increases the risk of hyperthermia (Gonzalez-Alonso et al., 1997; Nybo et al., 2001). Performance (Armstrong et al., 1985; Bardis et al., 2013; Cheuvront et al., 2007; Gonzalez-Alonso et al., 1997; Montain et al., 1992; Nielsen et al., 1981; Sawka et al., 2007) as well as pacing strategy (Altareki et al., 2009; Racinais et al., 2015; Schmit et al., 2016; Stearns et al., 2009; Tatterson et al., 2000) can decrease when body mass is reduced up to 4%, compared to performing in a euhydrated state. However, Goulet (2011) has shown that exercise-induced body weight loss of up to 4% does not decrease cycling performance, and drinking to thirst seems to maximize endurance performance. During marathon, ultra-marathon, and ultra-triathlon events, percent body mass loss of more than 2% did not hinder performance (Goulet, 2012).

Measurements of urine specific gravity can detect when cyclists are not in a euhydrated state at the start of their training session or competition because their body mass has decreased more than 1% and their perception of thirst sensation is activated, which is indicative of dehydration (Anastasiou et al., 2009). Hypohydration, detected by the brain as a change in plasma osmolality (Robertson et al., 1976), enhances neural activity as well as the conscious sensation of thirst in order to balance intra- and extracellular fluid spaces (Johnson, 2007; Sawka and Noakes, 2007).

Perception of thirst sensation as well as change in body mass are factors that will be measured and may provide insight of the hydration level of the participants. In a study by Yates et al. (2017), despite differences in pre-event hydration status, all groups that were investigated at the August 2015, 164-km Hotter ’N Hell Hundred (HHH) event had a similar drop in body mass; they all finished at approximately the same time. An increased blood flow to the skin, as well as sweat evaporation, allow body heat to be dissipated and leads to hypohydration, which reduces the risk for hyperthermia and plasma volume, but also increases cardiovascular and heat strain (Kenefick et al., 2010; Gonzalez-Alonso et al., 2000) and may compromise endurance exercise performance. When the effect of change of 1% body mass (considered mild dehydration) of cyclists was studied during an outdoor, 5-km hill climb in the heat, core body temperature was greater in dehydrated than in euhydrated cyclists (Bardis et al., 2013). A decrease in body mass as small as 1% (Bardis et al., 2013) or up to 3.9% (Armstrong et al., 1997) due to dehydration can decrease sweat sensitivity and influence thermoregulatory responses and a change in plasma osmolality (Armstrong et al., 1997; Kavouras, 2002). Euhydrated athletes presumably maintain a greater exercise intensity, which would yield an increased core body temperature; similar results have been shown among endurance athletes of other sports (Bardis et al., 2013; Casa et al., 2010; Maughan et al., 1985; Saltin et al., 1966).

Acclimatization

Acclimatization is another area that influences one's response after two weeks of training in new environmental conditions, such as heat, humidity, and/or elevation. Perceptual adaptations, including heat familiarization, may also yield improved endurance performance in the heat (Keiser et al., 2015; Schmit at al., 2016), perhaps independently of the usual indicators of heat acclimatization (Garrett et al., 2013; Lorenzo et al., 2010; Racinais et al., 2015). Rating of perceived exertion is another factor that will be measured in this study to inform researchers about the ability of the participants to safely complete the event, and may allude to their level of acclimatization. Adjustments in cardiovascular, metabolic, and thermoregulatory function help an individual become acclimatized (Nielsen et al., 1993; Nielsen et al., 1997; Périard et al., 2015; Shapiro et al., 1998).

Heat stroke

An individual is diagnosed with heat stroke when their internal body temperature is not thermoregulated and rises above the hypothalamic set point of 40°C (hyperthermia); has hot, dry or wet skin; and central nervous system abnormalities (delirious, convulsions, coma) that can lead to organ dysfunction (Bouchama and Knochel, 2002). Heat stroke can result from an elevated outdoor temperature (classic, non-exertional) or strenuous exercise (exertional) (Knochel and Reed, 1994). The thermal gradient due to sweat evaporation is necessary for heat transfer; elevated blood temperature increases cardiac output and, thus, ventilation (Knochel and Reed, 1994).

Perception of thermal sensation is another factor that will be measured throughout the HHH event to elucidate the relation between perception and gastrointestinal temperature. As blood circulates to the muscles and skin from central circulation for proper heat dissipation, there is a decrease in visceral perfusion in the intestines and kidneys (Rowell, 1983), which creates a competition issue as there is insufficient blood for muscle and skin. Concurrently, dehydration and salt depletion due to sweating impairs thermoregulation, so salt supplementation must occur (Deschamps et al., 1989).

Effective treatment of heat stroke is dependent on rapid transfer of heat from the core, to the skin, to the external environment, which occurs by cutaneous vasodilation (Rowell, 1983; Wyndham et al., 1959; Weiner and Khogali, 1980) via cold water immersion (Casa et al., 2007).

Cellular physiology

Although it is important to understand visible symptoms of individuals at risk for heat stroke, gaining knowledge of processes occurring at the cellular level helps researchers elucidate associations related to stress and performance that cannot be visualized during the event.

Cells respond to an increase in heat by producing heat shock proteins or stress proteins (Polla et al., 1998; Welch, 1992), which allows cells to survive the state of heat tolerance (Moseley, 1997; Polla et al., 1998; Welch, 1992). The circulation of immune cells may also be influenced by exercise in hot, humid conditions. Luk et al. (2016) demonstrated that there is a significant increase in leukocytes by the end of the 164-km cycling event, with the largest increase being in the neutrophil population, followed by monocytes and lymphocytes. Moreover, there is an increase in the concentration of platelets as well as markers for platelet activation, coagulation, and the fibrinolytic system. The increase in the fibrinolytic system balances blood homeostasis, which is a preventative measure of blood clot formation (Kupchak et al., 2017).

Heat shock protein 72 (HSP72) is a biomarker used to study the lasting impact of stress and the potential risk of exertional heat illness during exercise (Kampinga et al., 2009; Lee et al., 2017; Yang and Lin, 1999). Extracellular and cellular levels, studied by the CD3+ marker for peripheral blood mononuclear cells, demonstrated an association with markers of heat, exercise, and dehydration stress. Extracellular HSP72 decreased immediately following an exercise trial of moderate intensity treadmill walking and ergometer cycling, whereas cellular levels increased and remained at a higher level than baseline through 24 hours after the trial (Lee et al., 2017).

Cytokine levels also increase when heat stroke is present (Bouchama et al., 1993). Luk et al. (2016) studied the induced changes in circulating pro- (interleukin (IL)-1β, interferon-γ, tumor necrosis factor-α, IL-2, IL-6, IL-7, IL-8, IL-12, granulocyte-macrophage colony-stimulating factor) and anti- (IL-4, IL-5, IL-10, IL-13) inflammatory cytokine levels during the 164-km cycling event in hot, humid conditions. Furthermore, Luk et al. (2016) suggest that cyclists must reach their critical exercise intensity in order for environmental conditions to impact IL-10, so participants who finish the event faster might experience an acute transient immune suppression moreso than slower cyclists.

Gastrointestinal temperature assessment

Susceptibility to heat stroke can be measured using a variety of instruments, however measuring gastrointestinal temperature (T_{GI}) seems to be ideal (Casa et al., 2007; Hosokawa et al., 2016). Temperature is higher at the rectum and gastrointestinal tract due to blood flow returning from the muscles of the lower limbs via the pelvic cavity, thus this measurement is higher than the central blood temperature measured by esophageal readings (Mündel et al., 2014), and it has greater validity as an index of internal organ temperature (Byrne and Lim, 2007; Casa et al., 2007; Ganio et al., 2009; Hosokawa et al., 2016).

The ingestible, disposable pill technology used to measure temperature of the gastrointestinal tract by remote monitoring is a non-intrusive way to measure thermal strain (Gibson et al., 1981; Kolka et al., 1993; Lee et al., 2000; Livingstone et al., 1983; O'Brien et al., 1998; Teunissen, 2012). The pill is ingested by 11 hours prior to exercise (Mündel et al., 2014) to avoid the pill still being in the stomach or upper intestine, which would reflect esophageal temperature, which occurs when ingested closer to exercise start time (Byrne and Lim, 2007; Kolka et al., 1993; Lee et al., 2000). If the GI temperature cannot be read due to equipment failure, the alternative is to measure the rectal temperature (Mead and Bonmarito, 1949; Snow et al., 1993), which is also an accurate measurement of deep muscle temperature during lower-body exercise, such as cycling. Participants may decline this alternative reading, however, due to insertion difficulty (Aikas et al., 1962; Gass and Gass, 1998; Gibson et al., 1981).

Aside from cycling, thermistors are used to measure T_{GI} in a variety of athletic and professional settings in order to further investigate the safety of the individuals (Table 1.1).

Table 1.1. Studies that investigate T_{GI} to learn the risk of heat-related illnesses.

Activity	Reference
Rugby	Griggs et al., 2017; West et al., 2013, 2014, 2016
Football	Coris et al., 2009; Godek et al., 2004, 2005, 2006; Hitchcock et al., 2007
Hockey	Batchelder et al., 2010
Swimming	Hue et al., 2013; Peeling and Landers, 2006
Trail running	Lopez et al., 2001; Savoie et al., 2015
EMTs/ firefighters	Carter et al., 2007; Gallagher et al., 2012; Pryor et al., 2012
Bomb technicians	Stewart et al., 2011, 2013

The influence of the environment on endurance training

Unlike compensable heat stress, when the body is able to thermoregulate while working and maintain internal temperature, uncompensable heat stress results when the body cannot dissipate heat faster than it is generating heat (Dennis and Noakes, 1999; Kenney, 1985). As environmental temperature increases, uncompensable heat stress can impact performance. Furthermore, a hot-dry environment has lower vapor pressure as compared to a hot-humid environment; when ambient temperature exceeds 35ºC, convective heat gain results (Cheuvront and Haymes, 2001). There is greater evaporative heat loss in hot-dry environments, which helps avoid convective heat gain (Gagnon et al., 2013). When humidity and temperature increase, performance is further deteriorated (Helou et al., 2012; Maughan et al., 2012), especially among slower participants (Ely et al., 2007). Additionally, air movement is low, and solar radiation is superimposed (Levels et al., 2014; Morrison et al., 2014; Otani et al., 2016; Saunders et al., 2005). Concurrently, heat production may surpass the heat dissipation capacity and hyperthermia may result unless the athlete slows their speed and, thus, power output in order to reduce metabolic heat production (Périard, 2013; Périard and Racinais, 2015; Racinais et al., 2015). A comparison of performance with temperature, solar radiation, humidity, and wind speed may help identify if these indices are sufficient to determine the influence of the environment on performances that require high rates of metabolic heat production (Junge et al., 2016).

Compared to the last Saturday of August, when the HHH event usually occurs, the environmental conditions at HHH this August (of 2017) had the second lowest average temperature, similar wind speeds, and the highest average, minimum, and maximum humidity compared to the past seven years (Table 1.2), according to wunderground.com.

Table 1.2. Outdoor temperature in late August in Wichita Falls, TX.

Late August, Year	Ave. Temp (°F) (min, max)	Ave. Humidity (%) (min, max)	Wind speed (mph) ave., max
2010	80 (65, 96)	36 (17, 67)	8, 17
2011	83 (77, 91)	45 (31, 57)	7, 10
2012	84 (73, 95)	51 (30, 78)	13, 24
2013	85 (74, 96)	54 (29, 76)	5, 15
2014	86 (70, 104)	34 (14, 64)	8, 17
2015	88 (76, 101)	54 (28, 82)	11, 22
2016	76 (70, 84)	73 (49, 91)	7, 20
2017 (HHH day)	78 (70, 86)	75 (51, 93)	6, 14

Contribution of thesis study to the literature

There have been many studies performed at HHH (Table 1.3) that focus on factors examined in this study; but this study is focusing on the next step of learning the strength of association of some of these factors with T_{GI} during the ultraendurance event and also after a one hour recovery stage. Also, this study is novel because it is among the first to examine these associations with T_{GI} for a 164-km cycling event.

Table 1.3. Relevant studies conducted at past HHH events.

Research focus	Reference
Nutrition, Hydration, & Perception	Armstrong et al., 2012, 2014, 2015, 2015, 2016, 2017; Kunces et al, 2016; Moyen et al., 2015; Yates et al., 2017
Biomarkers	Kupchak et al, 2015, 2016, 2017; Luk et al., 2016, 2016; Vingren et al;, 2016
T_{GI}	Armstrong et al, 2012; Kupchak et al., 2017

CHAPTER 2: AN INVESTIGATION OF THE FACTORS ASSOCIATED WITH GASTROINTESTINAL TEMPERATURE OF CYCLISTS DURING THE 2017 HOTTER 'N HELL HUNDRED 164-KM CYCLING EVENT

Many factors associated with heat gain and heat loss will be investigated in this study. The Hotter 'N Hell Hundred (HHH) is an ideal venue to learn more about the association of these factors with gastrointestinal temperature (T_{GI}) because it is one of the largest single day ultraendurance events in the United States, and Texas has the second largest USA Cycling membership (USA Cycling). Furthermore, HHH participants range from elite to recreational, and from young adult to middle-aged to senior, which will provide information about different categories of cyclists. My aims and hypotheses for this study are as follows.

Statement of Research Aims and Hypotheses

Aim 1: Examine the association between gastrointestinal temperature (T_{GI}) and age, RPE, body composition factors, ride time, finish time, perception of thirst sensation, and perception of thermal sensation during an endurance cycling event.

Hypothesis, Aim 1: RPE, body composition factors, ride time, finish time, perception of thirst sensation, and perception of thermal sensation may increase as T_{GI} increases and may play a role in the change in T_{GI}; participant age may associate with change in T_{GI}.

Aim 2: Examine the association between T_{GI} and age, body mass, perception of thirst sensation, and perception of thermal sensation during the one hour rehydration recovery phase, after the event (REC).

Hypothesis, Aim 2: Body composition factors, perception of thirst sensation, and perception of thermal sensation may decrease at REC and may play a role in the change in T_{GI}; participant age may associate with change in $T_{GI.}$

Methods

Upon approval by the race director, researchers recruited participants of the 164-km distance during the registration session the day before HHH in Wichita Falls, Texas in August of 2017. Each cyclist was informed of all procedures, measurements, the time commitment, benefits, and risks of the study before providing their informed written consent (as approved by the Institutional Review Board for Human Studies at the University of North Texas and University of Connecticut). Study participants were not paid, and they were not provided advice about their cycling strategies, but they will receive full explanation of their own data and access to relevant manuscript publications in the future. Each study participant completed a medical history that was screened by the race medical doctor and research investigators. If participants had a history of musculoskeletal injury, exertional heat stroke, exercise-heat intolerance, gastrointestinal tract disease, or a gastrointestinal surgery, they were not included in the research study. All study participants confirmed they had previously completed at least one 164-km cycling event and were between ages 18 and 70 years old. The participants were to rely on their own hydration supplies during the event; the research investigators only provided water at the one hour post-race rehydration recovery phase (REC) to ask research questions regarding hydration differences during, versus one hour after, the event.

Anthropometric measurements were taken on recruitment day (DAY-1) and prior to the race start (PRE) (Table 2.1). Body mass (BM) was measured with a floor scale calibrated to ± 100g, age was recorded to the nearest year, and skinfold calipers were used for the 3-site skinfold test for males and females in order to measure percent body fat (Jackson and Pollock, 1978; Jackson et al., 1980). Gastrointestinal temperature (T_{GI}) was measured via an ingestible thermistor pill (CorTemp®, HQ, Inc., Palmetto, FL), which was swallowed by each participant after dinner on the night before the event so that the temperature sensor had time to migrate to the digestive tract by morning. T_{GI} is detected with the use of a digital thermometer (± 0.1°C), manually positioned near the posterior lumbar curve, to detect the thermistor pill. Participants were permitted to consume foods and fluids ad libitum and choose their own pacing strategy. The perception of thermal sensation (Young et al., 1987) included 17 categories of thermal comfort, ranging from 0.0 (unbearably cold) to 8.0 (unbearably hot) in 0.5 increments. The perception of thirst sensation (Engell et al., 1987) included 9 categories ranging from 1 (not thirsty at all) to 9 (very, very thirsty). Participants were also observed at the 97-km (MID) mark, at the finish (POST), and (Aim 2) one hour after the finish (REC). The 6-to-20 point rating of perceived exertion (RPE) scale (Borg, 1970) was provided to each participant at MID and POST to learn if their RPE was at or close to very, very light (6), or very, very hard (20).

Body mass, T_{GI}, as well as thirst and thermal perceptual ratings were also measured immediately after the finish (POST) as well as one hour later (Aim 2), after cyclists participated in a 650ml water rehydration recovery drinking protocol in an air-conditioned tent near the event finish, referred to as the REC time point. The water was stored at the finish line tent in the shade, thus it was not ice cold. Each participant received the same size water bottle, to drink within 3 minutes and remain at the finish line tent for the remainder of the hour for REC measurements. Four of the 37 participants did not finish the 650ml water within the 3 minutes, but since they participated, their measurements were included. This component of the study stemmed from a rehydration research question conducted by other members of the HHH research team.

Participants were not included in this study if only their DAY-1 or DAY-1 and PRE were collected, and if their measurements collected at MID or POST were not physiologically realistic, as compared with PRE. Participants were not included in the second study (Aim 2) if they did not complete the rehydration recovery protocol, and if their REC measurements were not physiologically realistic, as compared with POST. When 10% or less of a factor was missing, then values were incorporated for those participants based on the average for that factor.

SPSS (IBM SPSS, v. 25) was used for statistical tests at an a priori probability level of $p \leq 0.05$. Repeated measures ANOVA, paired sample t-tests, Pearson product moment (parametric) and Spearman rho (non-parametric) correlations, stepwise regressions, and linear regressions were performed. Effect size and power was calculated using G*Power3.1; with a sample size of 43 participants and effect size of 2.3, the power was 1.0 for Aim 1, and with a sample size of 37 participants and effect size of 1.6, the power was 1.0 for Aim 2. All data are presented as mean±SD.

Results

Aim 1: Examine the association between gastrointestinal temperature (T_{GI}) and age, RPE, body composition factors, ride time, finish time, perception of thirst sensation, and perception of thermal sensation during an endurance cycling event.

Table 2.1. Event data.	**DAY-1**	**PRE**	**POST**
Age (y)	51 ± 11.3		
Body Mass (kg)	87 ± 12.1	87.1 ± 12	85.4 ± 11.8
Body Mass Index (kg/m^2)	28 ± 3.3		
Height (m)	1.763 ± 0.06		
Body fat (%)	19.3 ± 5.7		
Finish Time (h)	6.4 ± 1.1 (anticipated)		6.1 ± 1 (actual)

Once participants were recruited (DAY-1), measurements were taken of 43 participants (41 males and 2 females) as detailed in Table 2.1. Body mass was also measured in the morning (PRE), immediately after (POST), and one hour after (REC, Aim 2). Other measurements are displayed in graph form.

Gastrointestinal temperature

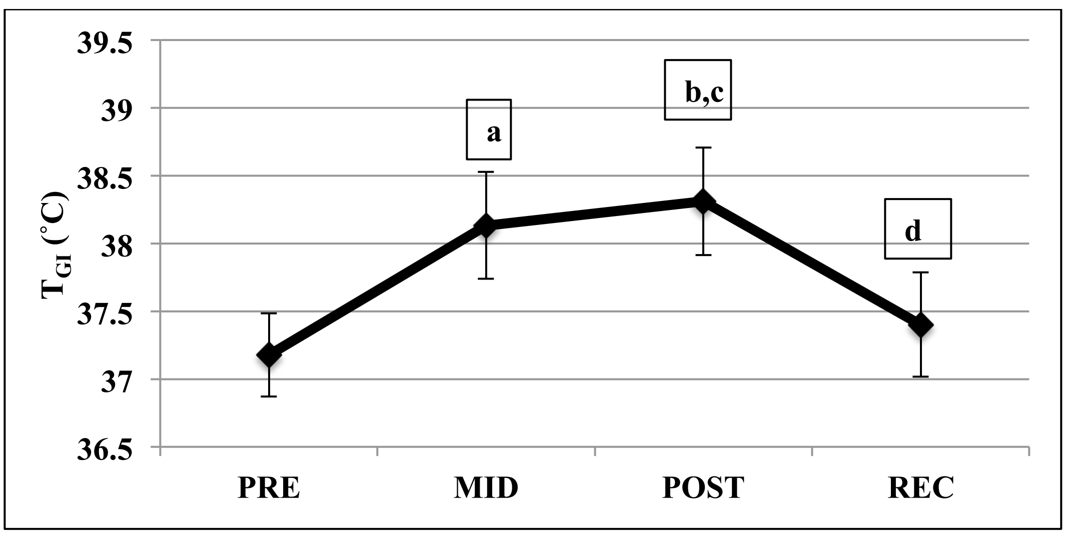


Figure 2.1. Temporal change in T_{GI}. T_{GI} increases as participants continue the 164-km cycle, and approaches PRE by REC. a, PRE to MID; b, PRE to POST; c, MID to POST; d, POST to REC.

T_{GI} increased from 37.2±0.3 (PRE) to 38.1±0.4 (MID) to 38.3±0.4 (POST) to 37.4±0.4 (REC) (Figure 2.1). All time points were statistically different from each other as determined by repeated measures ANOVA; paired sample t-tests indicated PRE to MID, $p < 0.001$; PRE to POST, $p < 0.001$; MID to POST, $p < 0.01$; POST to REC, $p < 0.001$ (Figure 2.1). The largest increase in T_{GI} occurred by the 97-km mark. The T_{GI} measurements of approximately 80% of participants increased up to 1.5˚C by POST (not shown). The highest POST T_{GI} recorded was 39.17˚C, a 1.4˚C shift in T_{GI} from PRE to POST, which is hyperthermic. Only three participants reached T_{GI} of greater than 39˚C, which suggests a majority of the participants were acclimatized to the event conditions, or the exercise intensity did not reach a level that resulted in uncompensable heat stress. These data were a key indicator that this study would focus more on which factors associate with T_{GI} of endurance cyclists, instead of being a heat stroke-risk study as originally intended.

Associations with change in T_{GI}

To learn about associations of different personal, physiological, and performance factors with change in T_{GI}, Pearson product moment parametric and Spearman rho nonparametric correlations were performed. ** indicates the correlation is significant at the 0.001 level and * indicates the correlation is significant at the 0.05 level (2-tailed). Across all time points (PRE through REC), RPE and age correlated with T_{GI} at $p < 0.05$ (Table 2.2), and the perception of thirst and thermal sensations correlated with T_{GI} at $p < 0.001$ (Table 2.3). When comparing PRE with POST time points, only perception of thirst and thermal sensations correlated with T_{GI} ($p < 0.001$) (Table 2.5). There was no association between T_{GI} and age, body composition factors (body mass (BM), % body fat, BMI, % change in BM (% Δ BM)), ride time, or finish time (Table 2.4). Interestingly, there is a strong correlation between BM and ride time ($p = 0.006$) and finish time (p= 0.018) (Table 2.4). When comparing MID with POST, RPE correlated with T_{GI} at $p < 0.05$ (Table 2.6). When comparing POST with REC, the correlation of age with T_{GI} approaches significance (Table 2.7), and only the perception of thermal sensation correlated with T_{GI} ($p < 0.001$) (Table 2.8).

Table 2.2. Parametric Pearson (R) Correlations (ALL time points)

		T_{GI}	BM	RPE	Age	% body fat	BMI	% Δ BM	Ride time	Finish time
T_{GI}	**R**	1	.023	.238*	-.196*	.012	.083	.019	-.081	-.102
	p		.801	.027	.011	.877	.286	.804	.299	.192
	n	166	123	86	166	166	166	166	166	166
BM	**R**	.023	1	-.325*	-.134	.292**	.851**	.066	.343**	.296**
	p	.801		.034	.140	.001	.000	.468	.000	.001
	n	123	123	43	123	123	123	123	123	123
RPE	**R**	.238*	-.325*	1	.014	-.125	-.028	-.251*	-.294**	-.336**
	p	.027	.034		.896	.252	.798	.020	.006	.002
	n	86	43	86	86	86	86	86	86	86
Age	**R**	-.196*	-.134	.014	1	.284**	-.013	-.115	-.116	-.017
	p	.011	.140	.896		.000	.868	.140	.138	.825
	n	166	123	86	166	166	166	166	166	166
% body fat	**R**	.012	.292**	-.125	.284**	1	.331**	.082	.222**	.270**
	p	.877	.001	.252	.000		.000	.296	.004	.000
	n	166	123	86	166	166	166	166	166	166
BMI	**R**	.083	.851**	-.028	-.013	.331**	1	-.030	.336**	.272**
	p	.286	.000	.798	.868	.000		.705	.000	.000
	n	166	123	86	166	166	166	166	166	166
% Δ BM	**R**	.019	.066	-.251*	-.115	.082	-.030	1	.223**	.369**
	p	.804	.468	.020	.140	.296	.705		.004	.000
	n	166	123	86	166	166	166	166	166	166
Ride time	**R**	-.081	.343**	-.294**	-.116	.222**	.336**	.223**	1	.887**
	p	.299	.000	.006	.138	.004	.000	.004		.000
	n	166	123	86	166	166	166	166	166	166
Finish time	**R**	-.102	.296**	-.336**	-.017	.270**	.272**	.369**	.887**	1
	p	.192	.001	.002	.825	.000	.000	.000	.000	
	n	166	123	86	166	166	166	166	166	166

Table 2.3. Nonparametric Correlations (ALL time points)

			T_{GI}	Thirst	Thermal
Spearman's rho	T_{GI}	**Correlation Coefficient**	1.000	.446**	.501**
		p	.	.000	.000
		n	166	123	123
	Thirst	**Correlation Coefficient**	.446**	1.000	.420**
		p	.000	.	.000
		n	123	123	123
	Thermal	**Correlation Coefficient**	.501**	.420**	1.000
		p	.000	.000	.
		n	123	123	123

Table 2.4. Parametric Pearson Correlations (PRE and POST)

		T_{GI}	BM	Age	% body fat	BMI	% Δ BM	Ride time	Finish time
T_{GI}	R	1	-.013	-.143	.051	.081	-.010	-.080	-.107
	p		.903	.189	.641	.456	.928	.466	.327
	n	86	86	86	86	86	86	86	86
BM	R	-.013	1	-.120	.291**	.850**	.063	.292**	.255*
	p	.903		.271	.006	.000	.562	.006	.018
	n	86	86	86	86	86	86	86	86
Age	R	-.143	-.120	1	.283**	-.011	-.141	-.175	-.079
	p	.189	.271		.008	.919	.194	.107	.471
	n	86	86	86	86	86	86	86	86
% body fat	R	.051	.291**	.283**	1	.329**	.091	.199	.248*
	p	.641	.006	.008		.002	.403	.067	.021
	n	86	86	86	86	86	86	86	86
BMI	R	.081	.850**	-.011	.329**	1	-.011	.324**	.268*
	p	.456	.000	.919	.002		.917	.002	.013
	n	86	86	86	86	86	86	86	86
% Δ BM	R	-.010	.063	-.141	.091	-.011	1	.260*	.394**
	p	.928	.562	.194	.403	.917		.016	.000
	n	86	86	86	86	86	86	86	86
Ride time	R	-.080	.292**	-.175	.199	.324**	.260*	1	.899**
	p	.466	.006	.107	.067	.002	.016		.000
	n	86	86	86	86	86	86	86	86
Finish time	R	-.107	.255*	-.079	.248*	.268*	.394**	.899**	1
	p	.327	.018	.471	.021	.013	.000	.000	
	n	86	86	86	86	86	86	86	86

Table 2.5. Nonparametric Correlations (PRE and POST)

			T_{GI}	Thirst	Thermal
Spearman's rho	T_{GI}	Correlation Coefficient	1.000	.555**	.544**
		p	.	.000	.000
		n	86	86	86
	Thirst	Correlation Coefficient	.555**	1.000	.561**
		p	.000	.	.000
		n	86	86	86
	Thermal	Correlation Coefficient	.544**	.561**	1.000
		p	.000	.000	.
		n	86	86	86

Table 2.6. Parametric Pearson Correlations (MID to POST)

		T_{GI}	RPE
T_{GI}	R	1	.238*
	p		.027
	n	86	86
RPE	R	.238*	1
	p	.027	
	n	86	86

Table 2.7. Parametric Pearson Correlations (POST to REC)

		T_{GI}	BM	Age
T_{GI}	R	1	.055	-.209
	p		.627	.063
	n	80	80	80
BM	R	.055	1	-.144
	p	.627		.202
	n	80	80	80
Age	R	-.209	-.144	1
	p	.063	.202	
	n	80	80	80

Table 2.8. Nonparametric Correlations (POST to REC)

			T_{GI}	Thirst	Thermal
Spearman's rho	T_{GI}	Correlation Coefficient	1.000	.201	.409**
		p	.	.074	.000
		n	80	80	80
	Thirst	Correlation Coefficient	.201	1.000	.189
		p	.074	.	.093
		n	80	80	80
	Thermal	Correlation Coefficient	.409**	.189	1.000
		p	.000	.093	.
		n	80	80	80

When stepwise linear regressions were performed with all factors for parametric study (age, BM, change in BM, BMI, percent body fat, RPE, ride time, and finish time), to learn of all associations with T_{GI}, the only associations were age (R^2= 0.106; p= 0.033), age and finish time (R^2= 0.195; p= 0.042), and age, finish time, and percent body fat (R^2= 0.368; p= 0.012). Thus, 10.6% of the variance in T_{GI} is explained by age, an additional 9% (19.5%) by both age and finish time, and an additional 26% (36.8%) by age, finish time, and percent body fat. Regardless of whether all time points (PRE through REC, PRE and POST, MID to POST, or POST to REC were studied, the same values were obtained.

Perception

The increase in perception of thirst and thermal sensations from PRE to POST, and RPE from MID to POST (Figure 2.2), were all statistically different from each other ($p \leq 0.001$) and suggest that the participants were under mild strain. The perception of thirst sensation increased to moderately thirsty, the perception of thermal sensation increased to warm, and rating of perceived exertion (RPE) increased to hard.

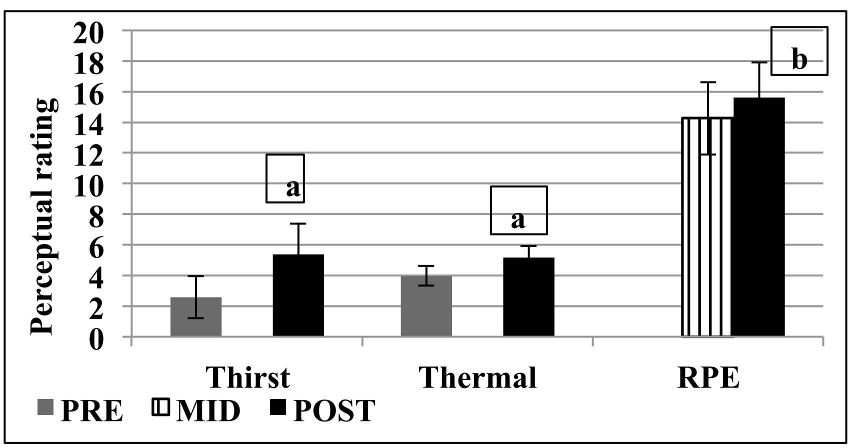


Figure 2.2. Temporal increase in perception indices. All data are presented as mean ± SD. p ≤ 0.001. a, PRE to POST; b, MID to POST.

Stepwise linear regression to learn if there was an association between perception of thirst and/or thermal sensation and T_{GI} across all time points indicated an R^2 of 0.180, $p < 0.001$ for thirst sensation and R^2 of 0.287, $p = 0.001$ for thirst and thermal sensation combined (not shown). Stepwise linear regression to learn if there was an association between perception of thirst and/or thermal sensation and T_{GI} at PRE and POST, indicated an R^2 of 0.318, $p < 0.001$ for thirst sensation and R^2 of 0.368, $p= 0.012$ for thirst and thermal sensation combined (not shown). Stepwise linear regression to learn if there was an association between perception of thirst and/or thermal sensation and T_{GI} from POST to REC, indicated an R^2 of 0.174, $p < 0.001$ for thermal sensation. When the Enter method was used instead of stepwise, which does not exclude values that are not statistically significant, R^2 was 0.040 for thirst sensation, $p= 0.075$, which is approaching significance, and R^2 was 0.185, $p < 0.001$ for thirst and thermal sensation combined (not shown). Stepwise linear regression to learn if there was an association between RPE and T_{GI} across all time points, which is only MID to POST, indicated an R^2 of 0.057, $p= 0.027$ (not shown).

Therefore, across all time points, 18% of the variance in T_{GI} was explained by the perception of thirst sensation, and 28%, an additional 10%, was explained by both perception of thirst and thermal sensations combined. Between PRE and POST, 32% of the variance in T_{GI} was explained by the perception of thirst and an additional 4% (36%) of the variance in T_{GI} was explained by the perception of both thirst and thermal sensations. Nearly 6% of the variance in T_{GI} was explained by RPE (MID to POST).

However, there were no associations with these perception indices at separate time points. PRE thermal and PRE thirst did not associate with PRE T_{GI} (R^2= 0.064; p= 0.102 and R^2= 0.010; p= 0.517, respectively). MID RPE did not associate with MID T_{GI} (R^2= 0.013; p= 0.471). POST thermal (R^2= 0.002; p= 0.797), POST thirst (R^2= 0.021; p= 0.355), POST RPE (R^2= 0.070; p= 0.087), POST thermal and thirst (R^2= 0.030; p= 0.546), and POST thermal, thirst, and RPE (R^2= 0.090; p= 0.290) did not associate with POST T_{GI} (Table 2.9). The association of POST T_{GI} with POST RPE approached significance, but POST T_{GI} did not associate with POST perception of thirst and thermal sensations (Table 2.9).

Body composition factors

The PRE to POST change in BM was minimal (Table 2.1) ($p < 0.001$), however the percent change in BM ranged from a loss of up to 4.4%, to a gain of 0.3% (not shown). Over 50% of participants lost between 1 and 3% BM, and nearly 20% lost between 3 and 4% BM. Correlation matrices indicate that BM and change in BM are correlated with ride time and finish time. However, change in BM (R^2= 0.001; p= 0.834), percent change in BM (% Δ BM) (R^2= 0.001; p = 0.832), BMI (R^2= 0.016; p= 0.426), and percent body fat (R^2= 0.019; p= 0.382) did not associate with T_{GI} at POST (Table 2.9). Percent change in BM did, however, associate with higher RPE at POST (R^2= 0.232; p= 0.001) (Figure 2.3). The perception of thirst and thermal sensations also did not associate with percent change in BM (R^2= 0.022; p= 0.343 and R^2= 0.069; p= 0.088, respectively).

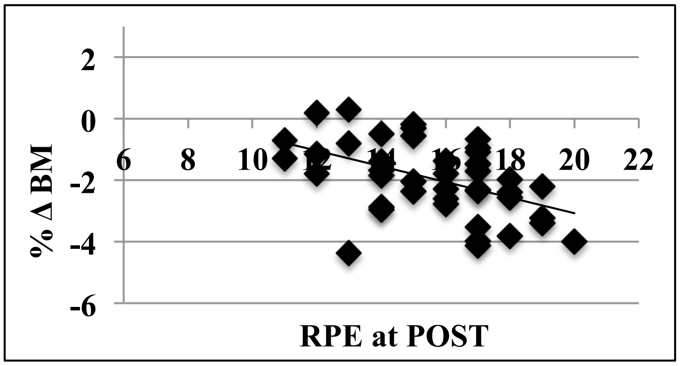


Figure 2.3. Greater percent change in body mass is associated with higher RPE at POST.
R^2= 0.232; p= 0.001

Age

USA Cycling reports that 35% of its over 45,000 members are between age 24 to 44 and 37% are between ages 45 and 64 (USA Cycling). A majority (56%) of the participants ranged from ages 51 to 59, 9% between 21 and 29, 5% between 34 and 39, 14% between 40 and 47, and 16% between 60 and 70 years old. Age did not have a strong association with ride time or finish time (R^2= 0.030; p= 0.263 and R^2= 0.006; p= 0.617, respectively) (not shown), which suggests that the effort used throughout the event was likely influenced by other factors. Age did, however, significantly associate with change in T_{GI} (R^2= 0.111; p= 0.029) (Figure 2.4).

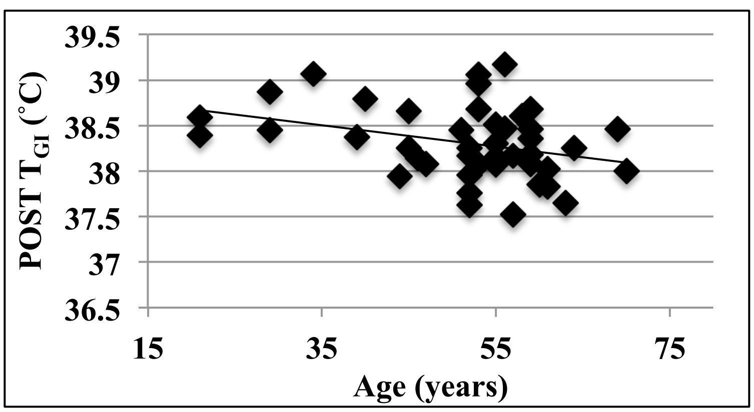


Figure 2.4. The association between age and T_{GI}.
R^2= 0.111; p= 0.029

Ride time and Finish time

Ride time is the duration of time the participant is cycling; finish time is the ride time plus the collective time of all breaks taken during the event. Finish time was actually faster than participants anticipated (Table 2.1), which is unlike other endurance events (Huggins et al., 2014). The fastest ride time was 4.10 hours (POST T_{GI}: 38.17°C); the fastest finish time was 4.5 hours (POST T_{GI}: 38.68°C). Neither ride time (R^2 = 0.052; p = 0.141) nor finish time (R^2 = 0.074; p = 0.078) had a strong association with T_{GI}, but finish time approached significance (Table 2.9).

Table 2.9. Factors associated with T_{GI} at POST	**R^2**	**p**
Thirst sensation	0.021	0.355
Thermal sensation	0.002	0.797
RPE	0.070	0.087
Thirst & Thermal sensations	0.030	0.546
Thirst, Thermal, & RPE	0.090	0.290
BM	0.001	0.834
% change in BM	0.001	0.832
BMI	0.016	0.426
Ride time	0.052	0.141
Finish time	0.074	0.078
% body fat	0.019	0.382
Age	0.111	0.029*

Aim 2: Examine the association between T_{GI} and age, body mass, perception of thirst sensation, and perception of thermal sensation during the one hour rehydration recovery phase, after the event (REC).

Table 2.10. REC data.	
Body Mass (kg)	85.1 ± 12.2
Thirst sensation	5 ± 2.2
Thermal sensation	4 ± 0.9
GI temperature (˚C)	37.4 ± 0.4

Once participants drank the 650ml water after the finish and remained in the finish area for one hour, measurements were taken as detailed in Table 2.10. Some of these measurements are also displayed in graph form.

Gastrointestinal temperature

At REC, participants were in an air-conditioned tent at the finish, drinking the prescribed 650ml water bottle, stored outdoors in the shade. T_{GI} significantly decreased from 38.3°C ± 0.4 (POST) to 37.4°C ± 0.4 once one hour had elapsed from arrival at the finish (REC) ($p < 0.001$) (Figure 2.1). The highest REC T_{GI} recorded was 38.15ºC, from 38.87ºC POST, and 37.43ºC PRE. Learning which factors are associated with change in T_{GI} from POST to REC is valuable for the rehydration recovery protocol of future participants.

Perception

The perception of thirst and thermal sensations slightly decreased by REC; the change in perception of thermal sensation from POST to REC was statistically different ($p< 0.001$), but not thirst sensation ($p= 0.528$) (Figure 2.5), regardless of completion of the rehydration recovery protocol. Correlation matrices indicated that only the perception of thermal sensation correlated with T_{GI} from POST to REC (Table 2.8). Stepwise linear regression suggested that 17% of the variance in T_{GI} was explained by the perception of thermal sensation; an additional 1.5% (18.5%) was explained by thirst and thermal combined, using the enter instead of stepwise linear regression method. However, T_{GI} played a role in the change in perception of thermal sensation (R^2= 0.139; p= 0.023) and thirst sensation (R^2= 0.212; p= 0.004) at REC (Figure 2.6, Table 2.11). The association with T_{GI} strengthened when both REC thermal and thirst were tested together (R^2= 0.299; p= 0.002) (Table 2.11).

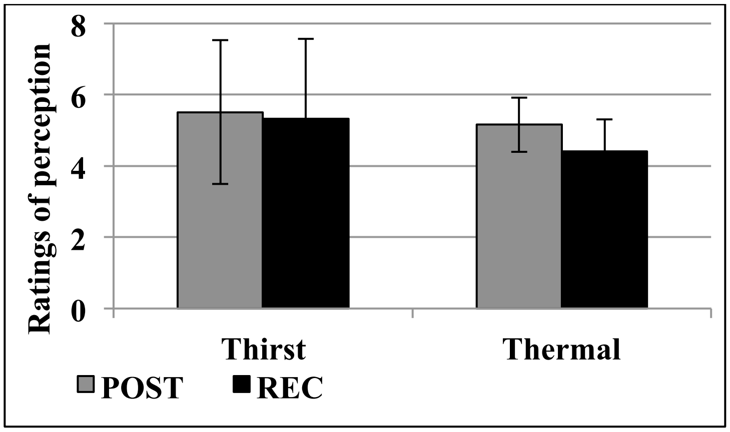
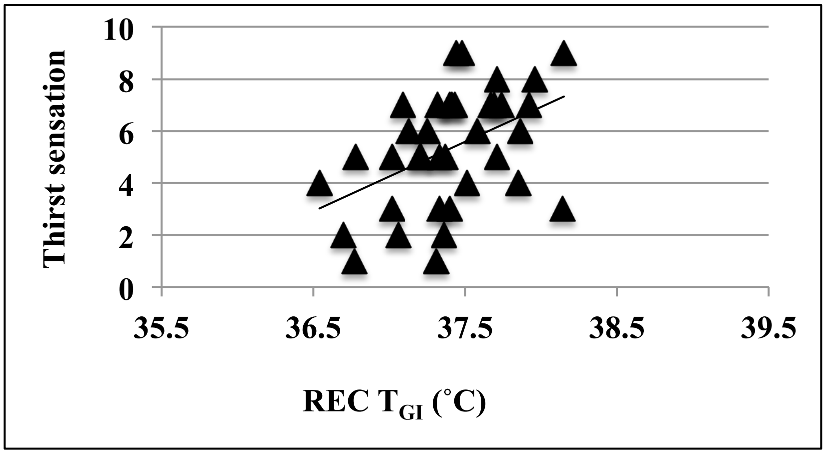


Figure 2.5. Perception indices at REC.



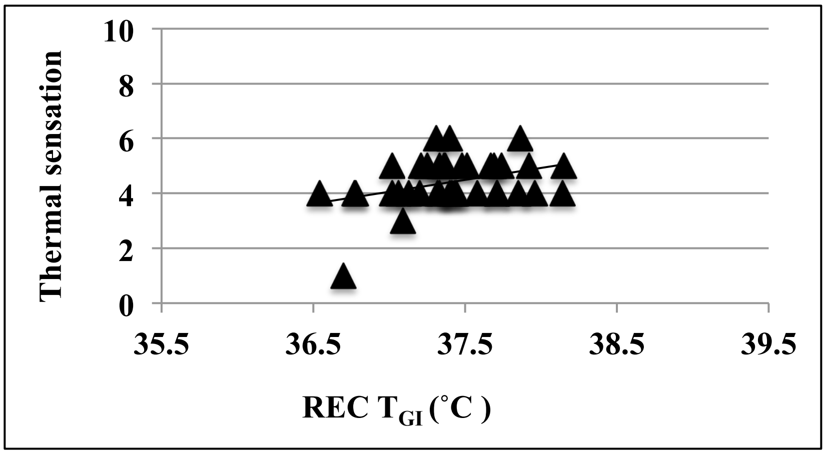


Figure 2.6. The association between T_{GI} and the perception of thirst and thermal sensations at REC.
Thirst: R^2 = 0.212, p= 0.004; thermal: R^2 = 0.139, p= 0.023.

Body composition factors

There was no significant difference in the change in BM from POST (85.4kg ± 11.8) to REC (85.1kg ± 12.2) (p= 0.897) (Table 2.10). Also, REC BM did not associate with change in T_{GI} (R^2= 0.014; p= 0.490) (Table 2.11).

Age

Correlation matrices show that the correlation between T_{GI} and age approaches significance (Table 2.7), but age did not associate with T_{GI} at REC (R^2= 0.067; p = 0.112) (Table 2.11).

Table 2.11. Factors associated with T_{GI} at REC.	R^2	p
Thermal sensation	0.139	0.023*
Thirst sensation	0.212	0.004*
Thermal & Thirst sensation	0.299	0.002*
Body mass	0.014	0.490
Age	0.067	0.112

CHAPTER 3: CONCLUSION & DISCUSSION

Conclusion

Across all time points, correlation matrices indicated that the perception of thirst and thermal sensations, RPE, and age correlated with T_{GI}. Stepwise linear regressions indicated that T_{GI} was associated with the perception of thirst and thermal sensation, and RPE was associated with T_{GI}.

Aim 1: Correlation matrices of PRE and POST only indicated a correlation of perception of thirst and thermal sensations with T_{GI}. Stepwise linear regressions performed of PRE and POST indicated a correlation of perception of thirst, not thermal, sensation alone with T_{GI}, and there was a correlation with perception of both thirst and thermal sensations combined. Linear regressions performed to learn about associations with T_{GI} at PRE suggested that T_{GI} did not significantly associate with the perception of thirst or thermal sensations. The correlation matrix and stepwise linear regression of MID to POST suggested that RPE correlated with T_{GI}. Linear regressions suggest that age had the greatest association with POST T_{GI}; finish time, RPE, ride time, BM, and the perception of thirst and thermal sensations did not associate with POST T_{GI}. Of the three perceptual ratings, percent change in BM only associated with RPE.

Aim 2: Correlation matrices of POST to REC indicated that only thermal sensation correlated with T_{GI}. Stepwise linear regression from POST to REC only indicated a correlation between T_{GI} and thermal sensation. When the Enter method was used instead of stepwise, thirst sensation approached statistical significance, and there is a significant correlation between T_{GI} and thirst and thermal sensation combined. Linear regressions performed to learn about associations with

T_{GI} at REC suggested that neither age nor body mass significantly associated with REC T_{GI}, but REC T_{GI} associated with the REC perception of thirst and thermal sensations.

Overall: Normal thermoregulation was sufficient to maintain T_{GI} and avoid heat stress in the compensable environmental conditions. Since the participants seemed to be acclimatized to this training distance and temperature of approximately 25.5ºC, even though they are likely not elite cyclists, their ability to perform without reaching or exceeding their limits is reasonable because of their training experience. The change in T_{GI} was greater from PRE to 97-km, than from 97-km to POST or from POST to REC. T_{GI} results indicate that participants were under mild strain. These data support the hypotheses that factors may increase with an increase in T_{GI} by POST, and decrease with T_{GI} by REC, and that age may be associated with change in T_{GI}. The factors studied are associated with T_{GI} across time points, but only age is associated with T_{GI} at the POST time point, and only the perception of thirst and thermal sensations are associated with T_{GI} at the REC time point.

A majority of what might be associated with change in T_{GI} from PRE to POST, and also back to PRE at REC, remains to be determined. Even though only minimal associations between T_{GI} and each factor were observed during the event and also at REC, and environmental conditions were not as hot as past HHH events, we deem these data as informative for the safety and performance of future endurance cyclist participants.

Discussion

Gaining a better comprehension of the factors that influence change of internal organ body temperature during an endurance cycling race is important for coaches, athletes, and elite and recreational cyclists alike. Originally, this was to be a study of endurance cyclists in the heat, but the temperature was not as high as the average temperature in late August over the past five years; the compensable conditions, of 25.5ºC, were not high enough for participants to be at risk for heat stroke illness (28ºC) (Binkley et al., 2002). The purpose of this study was to determine which event day factors, if any, associated with change in T_{GI} during the 164-km cycling event.

T_{GI} increased by event finish, with a majority of the change in T_{GI} happening by the 97-km mark, which suggests the participants exerted more effort until this point and maintained their pacing strategy for the remaining 67-km. Still, their exercise intensity did not achieve a level that would result in uncompensable heat stress. These T_{GI} data are similar to past HHH studies (Armstrong et al., 2012; Kupchak et al., 2017). Only three of the 43 participants had a POST T_{GI} of hyperthermic level; the highest POST T_{GI} was 39.17°C.

The perception of thirst and thermal sensation data findings at this event were similar to past HHH events (Armstrong et al., 2015; Armstrong et al., 2015; Armstrong et al., 2016; Armstrong et al., 2017). There was a significant association across all time points between perception of thirst and thermal sensations and T_{GI}, as well as RPE and T_{GI} as seen by correlation matrices and stepwise linear regressions. To further support that these data are representative of compensable conditions, POST T_{GI} did not associate with POST perception of thirst and thermal sensations. REC $T_{GI,}$ however, did associate with REC perception of thirst and thermal sensations. At this time point, the participants are in an air-conditioned tent and the body is working to stay warm while T_{GI} is decreasing back to PRE levels. A cold environment can suppress thirst sensation because of an increase in central blood volume to preserve body heat at rest, thus vasopressin is delayed (Cleary et al., 2014), but it must also be noted that perception of thirst and thermal sensation were not surveyed until the end of the one hour rehydration recovery stage, and the 650ml was given to participants to drink immediately after the finish. Rehydration can diminish thirst sensation within 15 minutes, but thirst returns to its pre-deprived feeling by 30 minutes after ingestion (Rolls et al., 1980). Therefore, when perception was measured at one hour, this is likely why a change in perception of thirst sensation was not seen. If perception of thirst sensation was asked within minutes of drinking the water bottle, a difference in thirst sensation from POST may have resulted, similar to previous work (Adams, 2016). The 650ml of water did not suppress thirst for one hour; more frequent perception measurements should be taken next time. Also, there is no wind (air flow) in the tent, as there was while cycling, so there was no heat loss or evaporation of sweat from the skin, hence the minimal change in thermal sensation at REC.

Age seemed to play a role in change in T_{GI}, as seen in the correlation matrix and stepwise linear regression of all time points, and linear regression of age and POST T_{GI}. This could be related to different hydration needs (Sawka et al., 2005; Winger et al., 2011; Yates et al., 2018) of older cyclists as compared with younger cyclists. Furthermore, maximal oxygen uptake and peak power output are lower, and maximal heart rate is higher among participants who are age 55 and older compared with ages 34 to 54 (Peiffer et al., 2008). Aging alters physiological control systems associated with thirst, so older adults may exhibit diminished thirst in response to hypovolemia (Kenney and Chiu, 2001). Aging is characterized by reduced homeostatic capacity;

changes in water intake and excretion can disturb salt and water balance (Rolls and Phillips, 1990). Furthermore, older adults have a reduction in their ability to conserve renal water and in their capacity to excrete water (i.e. more prone to hyponatremia) (Rolls and Phillips, 1990).

Body mass, percent change in body mass, body mass index, and percent body fat were tested to learn if any specific component of body composition associated with change in T_{GI}, but none of these factors associated with T_{GI}. This was not surprising since the body mass standard deviation at different time points was narrow. It was evident, however, that change in T_{GI} decreased as change in percent body mass decreased, and even though there was no association with T_{GI}, there was a significant correlation with ride and finish times between PRE and POST, and a significant association with POST RPE. These findings led to a curiosity about change in body mass as an indicator of dehydration and its impact on performance. 18% (8 participants) lost between 3 to 4% body mass, indicative of severe dehydration. Unlike previous studies (Armstrong et al., 1985; Bardis et al., 2013; Cheuvront et al., 2007; Gonzalez-Alonso et al., 1997; Montain and Coyle, 2002; Nielsen et al., 1981; Sawka et al., 2007), there was no correlation with performance or with T_{GI}, but Goulet (2011; 2012) has also demonstrated that performance does not differ if percent change in body mass is greater or less than 2%.

Aside from the 2015 and 2017 studies by Armstrong et al., in which the average finish time was 9.6 hours for 11 of 32 participants and 9 hours for all participants, respectively, the average finish time was similar to other HHH studies (Armstrong et al., 2015; Kunces et al., 2016; Kupchak et al., 2015; Kupchak et al., 2016; Kupchak et al., 2017; Luk et al., 2016; Luk et al., 2016; Vingren et al., 2016; Yates et al., 2017).

Limitations

This study elucidated which factors associated the most with T_{GI} at POST and at REC for an endurance cycling event in compensable conditions. The associations may have been stronger, or more factors may have associated with T_{GI}, in hotter, less compensable, environmental conditions. With regards to measuring the environmental conditions, these measurements are from the nearest weather station to the event route, Waverly Station, so the temperature, relative humidity, and wind speed on the course, over the 164-km route, may differ.

Individual participant tendencies may have also skewed the results. For instance, even though the participants had water bottles on their bikes and could drink to thirst, the researchers could not control the temperature of the fluids the cyclists ingested throughout the 164-km event, which can change T_{GI} (Wilkinson et al., 2008), only during the one hour rehydration recovery stage. However, at the rehydration recovery stage, all participants drank the water, so there was no negative control for this part of the study to determine the association of perception of thirst sensation with T_{GI} if they did not drink the water bottle. Additionally, if participants were not accustomed to reviewing perception indices, they may not have responded accurately to the survey.

The thermistor pills are known for their accuracy of detecting T_{GI}, however the detector for the thermistor pill may not always read. During those instances, the participants privately use a rectal thermometer to inform the researchers of their temperature for that time point, since rectal and T_{GI} are known to be very similar (Casa et al., 2007; Hosokawa et al., 2016).

Additionally, participants may have been acclimatized to the event day conditions, which was milder, yet more humid, than previous years and, thus, have better fitness than others. Overall, the range of fitness levels likely varied because this event is largely considered recreational rather than competitive, since most participants are not of elite status.

Future studies

If attempting this study in another year, these data can be utilized for insight into what factors may influence a change in T_{GI} in uncompensable environmental conditions. These studies can provide valuable foresight for future participants who plan to train for and safely complete the 164-km event.

This investigation did not focus on exercise intensity, so next steps can include investigating performance to elucidate the relation between intensity and change in T_{GI}, knowing that exercise intensity is related to metabolic heat production (Nielsen et al., 1990; Todd et al, 2005). VO_{2max}, peak power output, and heart rate relative to the level of fitness of each participant; split times; hydration status (urine analyses, body mass); and RPE can be evaluated throughout the event.

Approximately 5% of study participants were female; overall, females possess only 15% of USA Cycling memberships (USA Cycling). Being able to recruit a sufficient number of males and females will allow for studies that compare and contrast how cyclists perceive and perform during endurance cycling events; it would also follow up on prior research investigations at this event (Armstrong et al., 2016).

CHAPTER 4: REFERENCES

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