Spring 2020

A Comparison of Sweat Rate and Sweat Electrolyte Concentrations Between Two Modes of Exercise in Trained Triathletes

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A Thesis

Presented to the Faculty of the

Department of Sports Medicine

West Chester University

West Chester, Pennsylvania

In Partial Fulfillment of the Requirements for

The Degree of

Master of Science

By

Daniel Webb

May 2020

Acknowledgements

I would first like to thank my master's thesis committee chair, Dr. Sandra Fowkes Godek for opening the door to the world of research and giving me the opportunity conduct research in the HEAT Institute for the past 2 years. It truly has been a privilege to work with you throughout this master's thesis. To my committee members: Dr. Nicole Cattano and Dr. Katherine Morrison, thank you for keeping me on track through this journey and allows available for guidance.

My success and completion of my master's degree would have not been possible without the love and support of my family and Deonna. Thank you for the encouragement and sound words of advice.

Abstract

A Comparison of Sweat Rate and Sweat Electrolyte Concentrations Between Two Modes of Exercise in Trained Triathletes.

By Daniel Webb

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Context: Sweat rate and sweat electrolyte concentration are traditionally collected for one exercise bout. The purpose of this study determined whether sweat electrolyte concentration and sweat rate varies between two modes of exercise. **Methods:** Twenty subjects (10 male/ 10 female) completed 2 training sessions, one hour of biking and one hour of running in a thermal neutral environment. Sweat samples by absorbent patches were used and collected at the end of exercise or when the sweat patches became full. **Results:** No differences in sweat rate (Bike = 1.12L/hr ± 0.58, Run 1.12L/hr ± .55, $r(38)=.80$, $p = 1.00$) but a significant difference between sex (Bike males = 1.52 ± .49, Bike females = 0.72 ± .36, Run males = 1.57 ± .35, Run females = 0.67 ± .23, $p = <.001$). No difference between trial in sweat electrolyte composition (Na^+, Cl^-, K^+). **Conclusion:** Total sweat electrolyte concentration and sweat rate does not change during running or biking.

Table of contents

Lists of Tables

Lists of Figures

Chapter one:

Literature review

Thermoregulation

Thermoregulation or temperature regulation is the body's response to a thermal load, by acting through an effector response, to maintain homeostasis [1,2]. The effector response is shivering, sweating, and vasomotor changes [2]. For this literature review, only sweating in response to a thermal load will be used for thermoregulation. Regulation of core body temperature (T_c) is considered vital organs and head and trunk[2]. Measuring T_c is achieved through various methods; oral, tympanic membrane, rectal, esophageal, hypothalamic, or central blood temperature[2].

An athlete during exercise will create large amounts of heat produced by muscle contraction as a byproduct of metabolism[1,3], especially true if an athlete is performing a steady-state exercise. Core temperature during a steady-state will rise linearly to metabolic rate and an increase in the level of exercise[2,3]. The rise in T_c will first be recognized by the hypothalamus[1-4, 6, 12]. The heat produced by working muscle will be carried away via the venous drainage system[2,3].

Within the hypothalamus, there is a set core body temperature that the body uses a reference point during exercise[2,4]. The setpoint is a concept that describes the control of thermoregulation within the body[4]. When the hypothalamus recognizes an increase in core temperature, one of the first mechanisms is sweating and increase in skin blood flow (vasodilation/ vasoconstriction)[4]. The earliest response is vasoconstriction of the superficial veins[2]. As the thermal load increases, sweating and vasodilation begin, and skin blood flow to the limbs is the greatest to try to dissipate the heat[2].

Vasodilation is an essential concept for cooling the core. When T_c rises above 37°C[1], the body will begin to sweat, as well as, vasodilate blood vessels[8]. Warmblood from the core is distributed to the skin[3]. The warm blood at the skin surface will lose heat (being cooled) through convection at the skin surface[3]. The blood that is cool, at the skin surface, is carried to the core where T_c will fall[3]. Increase of skin blood flow will cause more significant vasodilation of the vessels which, opens new skin capillaries; these new capillaries will allow a more considerable amount of time for heat dissipation to the ambient air through convective cooling[3].

If the ambient air temperature is 28°C, increase skin blood flow will be the primary method for cooling the body[3]. Therefore, vasodilation is limited to the surrounding ambient air temperatures[3]. However, if the ambient air temperature is higher than T_c, then the body will store heat[3], causing a reversal in heat exchange, and heat is stored within the body, resulting in an increased core body temperature[3]. Therefore, the body must try to cool itself off from sweating. Activation of vasodilation and sweat glands is key to keep the body cool.

I. Sweat glands

Apoeccrine, apocrine, and eccrine glands are all different type of sweat glands[1,5]. Apoeccrine and apocrine are limited to specific regions on the body (axillae region) and are not responsible for thermoregulatory sweat and only become active at the start of puberty [1,5,6]. Therefore, only the eccrine gland will be the focus of this literature review, and we refer to as sweat glands.

Humans have approximately 1.6 – 4.0 million eccrine glands[1,5,7], and the distribution of the eccrine glands over the body is the greatest in the palms of hands and feet, forehead, following upper limbs, and finally lower limbs and trunk[5,6]. The size of the sweat glands varies both individually and regionally[6]. However, sweat gland density decrease with body surface area[1].

Sweat glands have a secretory coil and a duct[1,5,6], tubular epithelium make up the two structures[1]. The secretory coil is located in the lower dermis, while the duct extends through the dermal layer and then opens to the skin surface[5]. The size of an adult secretory coil ranges from 30 – 50 µm in diameter and 2 – 5 mm in length[5], while the size of the duct ranges 1 to 8 X 10^{-3} mm^3[3,5]. A positive correlation has shown between maximal sweat rate and glandular size[5,6].

II. Heat balance theory

The heat balance theory is how the body maintains equalibrium[1]. The body cools primarily from the evaporation of sweat from the skin surface. Factors that impact body heat gain or loss are clothing or equipment, body composition, and body size will directly modify sweat rate[1,8].

The following equation is evaporative heat loss (E_{req}) formula

$$E_{req} = M - W \pm (R + C + K)$$

M refers to metabolic energy expenditure. Metabolic expenditure is the total rate of energy used during oxygen consumption[1]. Metabolic heat expenditure is the most significant contributor to a rise in core temperature during exercise[1,3]. W is external work. Work is the rate at which external work (force X distance) is being perfromed[1]. R is radiant heat exchange. Radiation can either give the body heat or cause heat loss occurring through the skin or clothing and the surrounding surfaces[1]. C is convective heat exchange. Convective heat exchange is the movement of air past the body[1]. Convection will have the most effect on cooling the body during exercise. K is conductive heat exchange. Conduction is the transfer of heat to the surface by direct contact with the body or clothing[1]. Radiation, conduction, and convection rely on environmental conditions.

III. Hydration

Hydration plays a critical role in thermoregulation. An individual's total body water counts as 60% of their weight[9]. Therefore, everyone has a day-to-day variation in their total body weight, hypohydration (less water in their body), or hyperhydration (more water in their body) that exceeds normal euhydration of approximately ± 0.2 – 0.5% of total body mass[9]. Daily water loss occurs through urinary/ fecal, respiration, and sweating, known as dehydration[9]. Dehydration is the process of losing water[10]. Dehydration through exercise occurs primarily through sweat. For example, an individual can start an exercise bout already below their normal euhydrated state (hypohydrated), because their total body water is low from the previous exercise, they will become more dehydrated with exercise[9]. Starting an exercise bout already hypohydrated can have serious effects.

The state of being hypohydrated has found to increase body heat storage while at the same time, decrease an individual's tolerance to exercise in the heat[9]. Since water stores heat, and when the core temperature is above 37°C, in a hypohydrated individual, it increases the core temperature quicker and higher because there is less fluid in the body to store the heat, putting them at risk of a heat illness[10]. An increase is core temperature reduces the blood flow to the skin, thus leading to a hypovolemic state[9,11].

Hypovolemia during exercise commonly occurs during exercise through sweating and also through the movement of blood or fluid to the interstitial space surrounding the muscle[3,11]. Nadel et al.[11] found that an extensive exercise, there is a relationship between forearm skin blood flow and core temperature. The researchers found that when compared to a hyperhydrated and control (euhydrated) individual, hypohydration has a decrease in forearm skin blood flow and a higher core temperature[11]. The decrease in skin blood flow to the forearm will affect how the body cools during convective heat loss.

Sweating

As the body losses water via sweating, numerous minerals are lost. Researchers have determined that sodium (Na^+), potassium (K^+), chloride (Cl^-) are most commonly studied. A rise in body temperature initiates thermal sweating[5,12]. As stated previously, the sweating response correlates with the central thermoregulator within the hypothalamus[1-3,12]. Sweat initiation begins when the hypothalamus detects a T_c of 37°C [1,5]. Studying the neural tracks in humans is hard to understand because it is not entirely understood, but evidence in animal studies suggest that nerves surrounding the eccrine gland are nonmyelinated class C sympathetic postganglionic fibers[1,5]. Acetylcholine is the primary neurotransmitter that stimulates the C fibers[1,5,7,12]. In addition to sweat stimulated through a rise in T_c, the eccrine sweat gland has shown to be stimulated by non-thermal sudomotor responses mediated by a feed-forward response regulated by mechanoreceptors, osmoreceptors, and baroreceptors[1].

When the activated eccrine sweat gland becomes stimulated, a release of acetylcholine that diffuses into the presynaptic terminal, which enters the gland via intercellular canaliculi[12], the ramification from the release of acetylcholine causes an influx of calcium ions enters and stimulates the pumping of sodium ions into the cell[12] and increases the permeability of potassium and chloride channels[5]. Water that is resting in the interstitial space follows the sodium, due to osmosis[12]. Sodium potassium pumps, located in the luminal membrane, are activated when they reach their threshold potential[12]. The pumps actively transport sodium, along with chloride and water, to the skin surface[12].

Sweat is primarily isotonic with blood/ interstitial fluids[1,5,12], but eccrine glands can actively reabsorb ions[1,12]. Reabsorption occurs in the duct[12]. As the sweat is making its way to the surface of the skin, sodium passively reabsorbed via epithelial sodium channels on the luminal membrane[1,13]. Sodium is also actively reabsorbed through sodium/ potassium-ATPase transporters on the basolateral membrane[14]. The cystic fibrosis transmembrane conductance regulator passively reabsorbs chloride[1]. Aldosterone is the primary hormone that is responsible for the activity of the reabsorption transporter[1,15]. Reabsorption is also related to sweat rate [1,5]. The higher the sweat rate, the less reabsorption occurs, resulting in a more significant surface sweat electrolyte concentration. Vice versa, the less significant the sweat rate, the higher the reabsorption rate is resulting in a lower surface sweat electrolyte concentration.

I. Heat Acclimation

Exercising in the heat can affect the physiology of the eccrine sweat gland [1,16]. Sweat rate, as well as, sweat composition was the first to be studied and reported on in the study of acclimation[4]. Heat acclimation develops through repeated exposure to a thermal environment, which will reduce the likelihood of the adverse effect of heat stress[4]. Heat acclimation will cause an increase in sweat rate as well as decrease sweat chloride and sodium concentrations[4,16]. Exercising in the heat shifts the onset of sweating, which can occur at a lower T_C[4,17,18]- this shift in an adaptive response to central and peripheral mechanism[4]. Meaning, exercising in a thermal environment will decrease core body temperature (central), as well as an increase in the onset of sweating and increase skin blood flow (peripheral)[4]. The peripheral adaptations occur at the sweat gland level. Adaptations that occur can improve cholinergic sensitivity and increase the size and efficiency of the eccrine sweat gland[4,6]. Since there is the onset of an increase of sweating at a lower core temperature, the sweat glands can adapt against hidromeiosis[4,19]. Hidromeiosis is a saturated epidermis (stratum corneum), which suppresses sweating[20].

As mentioned previously, sweat electrolyte concentration decreases with repeated thermal training[4], due to the sweat gland being able to reabsorb Na^+ and Cl^- more efficiently, resulting in a more dilute sweat[4,19,21,22]. For example, an unacclimated individual may have a sweat sodium concentration of 70 mmol/l. With proper training in the heat, the sweat gland will adapt and be able to reabsorb more sodium giving this individual new sweat sodium of 15 mmol/l. Changing the sweat electrolyte concentration of sweat will lower the water vapor pressure and will allow for the sweat to be evaporated easier because of the gradient between the air and the sweat[23].

Within the research on heat acclimation, repeated training in the heat will affect sweat rate and sweat sodium ($SwtNa^+$). Buono et al.[22] studied the effect of heat acclimation on sodium ions of healthy individuals. The conclusion of this study leads the researchers to report that heat acclimation increased the sodium reabsorption rate within the sweat duct[22]. They hypothesized that when the body acclimated to a hot environment, it produced a more diluted sweat[22]. Once acclimated, the body will secrete fewer mineral solutes and thought the body would store these solutes in the extracellular space[22]. The extra pressure within the extracellular space (increase in osmotic pressure) will push the solutes into the cell[22]. Being able to have a reduced $SwtNa^+$ secreting may lead to an individual being able to have a more maintainable thermoregulatory sweat rate (SwR) and skin blood flow process while exercising in the heat[22].

II. Sweat rate measurement

Sweat testing has been extensively studied and tested regarding their methodology and reliability[1]. There are two ways to measure sweat rate, local sweat rate (SwR_L) and whole-body sweat rate (SwR_{WB}).

There are two ways to measure the SwR_L. The first method to measure SwR_L is hygrometry. Hygrometry or ventilated sweat capsules pump dry air into the capsule with a known temperature, and measures the change in temperature of the water vapor that is pumped out[1]. Limitations of this method do arise. This method creates a microclimate[1]. The microclimate can overestimate SwR_L because the ventilation creates dry skin, which stimulates sweating[1].

Gravimetric is the second method of measuring SwRL [1,24]. Gravimetric involves collecting sweat on the skin surface using absorbent patches[24] filter paper, Parafilm-M pouches, cotton gloves/socks, or plastic sweat collector[1]. With those methods, the difference in mass of the saturated sweat patch between pre-exercise and post-exercise weight determines SwR_L[1]. The patch is removed when is appears to be soaked in sweat[1,8] or after the completion of exercise session[24-26].

Limitations to gravimetric techniques also arise because of the adhesive film collects the sweat. The adhesive film creates a microenvironment and ultimately traps the sweat inside[1]. Trapping the sweat on the surface will increase the rate of hidromeiosis[1,24].

Regional variations do exhibit but are similar for males and females[27]. A study by Havenith et al.[27] found that the sweat rate of the extremities (arm) was significantly less when compared to the sweat rate of the torso (chest, sides, and back).

Finding a reliable body placement to measure SwR_L to estimate SwR_{WB} is an issue. Each local site across the body produces different SwR_L[24]. Mid-back, chest, and forehead then to overestimate SwR_L, while the forearm is the most accurate to estimate for SwR_{WB}[1,24] due to the vast differences in sweat gland density. A particular region of the body will have a higher density of sweat glands when compared to another region[24]. The eccrine glands' ability to secrete sweat remains the same, but there is a more significant density (number) of the sweat gland. The more glands in an area, there will be an increase in SwR_L[1]. Baker[1] found that SwR_L could be used to are an economical and reliable method to determine SwR_{WB}. However, her conclusion is only reliable after 30 minutes of exercise[1].

The most practical and method of obtaining SwR_{WB} is by subtracting the subject's body mass before to exercise to their body mass after exercise[1,8,24,25,28,29]. Nude body mass is necessary if clothing is soaked or if conducting a field study. Weighing with clothing or other equipment worn will drastically overestimate calculations by 10%[1]. Urine output, fluid intake and exercise time is also accounted for SwR_{WB} calculation[1,8,24,25,28,29].

III. Sweat Electrolytes collection

Whole-body washdown (WBW) is considered to be the most accurate method of sweat electrolyte collection. A study done by Shirreffs and Maughan[28] collected sweat through the WBW method. The researchers strongly recommended using this method to collect sweat samples because sweat is not absorbed into clothing, dripped off the body, and does not interfere with natural evaporative process [28]. The researchers constructed a sweat collection apparatus made out of polyethylene[28]. This apparatus collected all sweat that ran off the subjects but also allowed for a natural evaporative process to occur[28]. Before entering the sweat collection apparatus, each subject was washed with 4 liters of deionized water and then dried with a towel[28]. The subjects would only exercise until they lost 2% body mass, which lasted from 55 – 135 minutes[28]. Upon completion of the exercise bout, each subject washed with 4 liters of deionized water and took off all clothing and left the clothing at the bottom of the apparatus[28]. The researchers took sweat samples from the bottom of the bag[28]. This mixture would give an accurate representation of whole-body sweat loss[28]. A limitation of using this method of sweat collection is that it can be used only in the laboratory setting, and subjects can only use a cycle ergometer[1,14,28].

Since the WBW method was limited to the laboratory setting, other methods of sweat electrolyte concentration analysis need to occur in a field study. Patterson et al.[24] wanted to determine which anatomical sites are most accurate when compared to the WBW method. As state previously, the body's distribution of sweat glad density differs across the body[24], which will affect sweat electrolyte concentration. Patterson et al.[24] tested ten anatomical sites. Forehead, chest, scapula, abdomen, lower back, forearm, hand, thigh, calf, and foot. Their results showed that three anatomical sites that could provide an accurate representation of whole-body sweat electrolyte loss, forearm, thigh, and calf[1,24]. Researchers usually remove the sweat patches once they have become saturated or at the end of practice[1]. However, research has found that there was no significant difference if the absorbent patches were removed 30 minutes into the exercise bout or 70 minutes[1].

IV. Individual considerations

Both SwR and sweat electrolytes vary among individuals. Both males and females of various ages have very individual differences in sweat electrolytes[30]. Research has shown that males have a higher incidence of onset of sweating[1,8,31], thus potentially having a higher secretion rate of Na^+ [30]. Meyer et al.[30] reported that prepubescent males and females have lower amounts of sweat Na^+ and Cl^- but have higher K^+ levels when compared to adults. They concluded that this was due to the maturation of the eccrine sweat gland and its ability to reabsorb sweat electrolytes and the transportations properties of the sweat gland[30]. Aldosterone levels within the duct were lower in the prepubescent population when compared to the adult population[30].

Aerobically trained versus untrained population was looked into by Hamouti et al[25]. In their study, they conducted a cycle-test. Their research found that trained individuals tended to secrete more Na^+ than untrained at a higher exercise intensity[25]. When there was a spike in exercise intensity, the untrained individual had higher sweat sodium levels than trained individuals[25].

If an individual is secreting large amounts of sodium when sweating, their body fluid balance may be difficult to maintain[8]. Supplementing with salt may aid in the prevention low blood sodium and plasma volume[8]. An introduction of a high sodium diet may aid in reversing the expected fall in sweat sodium when sweating, particularly in the heat[8].

For sports medicine professionals working with and around athletes, it is particularly important to be aware of how much sweat sodium an athlete is losing as well as how much the athlete is replacing the lost Na^+ through dietary supplementation. More tremendous athletes may be consuming a large amount of sodium due to them consuming more calories than smaller athletes, but that is not always the case[8]. An increase in Na^+ desire may be correlated with hypohydration and deprivation[8].After intense exercise, these athletes may increase their desire for salt and fluids[8]. A severe loss of Na^+ during exercise can be described as exercise-associated hyponatremia (EAH) or hyponatremia of exercise[8, 32].

Exercise associated hyponatremia is a clinical condition in an athletic population or general population where blood sodium concentrations drop below 135 mmol/l [8, 32]. Athletes who have a high sweat rate might think they need to replace their loss with more fluid. However, these athletes are putting their wellbeing in danger. High rates of fluid consumption, consuming hypotonic fluids, are hazardous in individuals who consume to much over a single exercise bout[32]. Due to the sudden increase in fluid in the extracellular space relative to the sodium content[32], it will dilute the blood Na^+.

Some health care professionals believe that sports drinks that advertise as an electrolyte replacement source are the answer for sodium replacement[8]. However, these sodium replacement beverages do not contain enough sodium to restore the body to normal levels effectively[8]. The body has defense mechanisms that can protect against rapid sodium depletion during exercise[33]. The body will immediately release sodium stores from the internal body stores, as well as matching extracellular fluid that equals 140 mmol/l of sodium[33]. However, there is limited research regarding information on the sodium stores within the body[34]. This process is individualized, and some individuals cannot adequately utilize their stores, which will lead them closer to a hyponatremic state[34].

Body characteristics were looked into by Havenith et al.[35] In their study, their subjects cycle on an ergometer. Their research found that there is no relationship present when comparing sex and adipose tissue when looking at sweat loss[35]. However, when

Havenith et al.[35] compared body surface area (BSA) to sweat loss, they found a significant correlation.

An individual with a high BSA will be able to dissipate heat not as well when compared to an individual with a low BSA[31]. Square root of height (cm) times weight (kg) over 3600 is the formula for body surface area. Godek et al.[31] looked into American football athletes and cross-country runners. These two groups of athletes have different demographics[31]. The American football players have a bigger body size than the cross-country runners. The researchers conclude that American football athletes have a higher sweat rate when compared to the cross-country runners due to American football players having a greater BSA; this is due to a more significant number of sweat glands[31].

Due to the research available, the sweat rate is dependent on body size (BSA)[1, 8, 31]. Males would have a higher sweat rate when compared to females. Since females will have a smaller BSA when compared to males. Males are have a more considerable amount of metabolic heat production when exercising[36, 37]. Males and females have the same number of eccrine glands[36], but females have a lower sweat rate, due to lower BSA[27]. In a study by Avelline et al.[27] the researchers found that when males and females exercised, males have a more significant metabolic workload and aerobic capacities, and males are more waste full sweaters[8,31]. Males would have a higher sweat rate, because the sweat would drip off the body; this is waste full sweating because of the sweat is not evaporating off the body for a cooling mechanism[8,31].

V. Comparison

Although no articles compare sweat rate or sweat concentration within the same individual performing two different modes of exercise, there are a few studies that studied sweat electrolyte concentrations comparing groups of people.

Godek et al.[8] studied sweat rates and sweat sodium concentrations in three groups of American football players. The authors looked at backs and receivers, linebackers and quarterbacks, and linemen[8]. Sweat rate variation's between positions were due to BSA[1, 8, 31]. There was no difference in sweat sodium, but value ranges from 15 – 99 mEq/L[8]. Since sweat rates were different within groups, sweat sodium loss was the greatest for the linemen[8]. The authors have shown that sweat sodium is highly individualized, and heavy, salty sweat needs an increase of sodium in their diet[8].

Henkin et al.[26] looked at sweat sodium concentrations and sweat rate in 3 groups as well, athletes, swimmers, and nonathletes. In order to match groups, the runners and swimmers would be exercising in their respective sport for 2 hours a day for 5 days a week, while the nonathletes could only weight train for 3 days a week[26]. The authors concluded that the runners had the highest sweat rate at 1.5 ± 0.2 L per hour, while the nonathletes had the lowest sweat rate at 0.6 ± 0.2 L per hour. The swimmers and nonathletes shared similar sweat electrolyte concentrations (65.4 ± 5.5 and 67.3 ± 8.5, respectively)[26]. The authors concluded that since runners were already acclimated to running, they exhibited a higher swat rate and lower sweat electrolyte concentration; conversely, the aquatic environment might have limited body heat transfer, which resulted in limited sweating[26].

VI. Disorders of Sweat glands

Hyperhidrosis is in individuals who experience abnormally large amounts of sweat from their palms and soles or their feet[38]. This condition occurs when someone is experiencing social and or occupational distress[38]. Hyperhidrosis does not occur during sleep or sedentary activity[38]. Interestingly enough, hyperhidrosis of the axillae can occur to[38]. However, sweat from these glands occurs through apoeccrine[38]. Hyperhidrosis of the axillae has led researchers to believe that large amounts of sweat from this region do not have an increase in odor[38]. They are suggesting that excessive sweating washes away the odor-producing properties of sweat[38].

On the other end of the spectrum, there is a condition called hypohidrosis or anhidrosis. Anhidrosis is a clinical condition where an individual cannot produce or deliver sweat to the surface of the skin[38]. Individuals who have localized or full-body, anhidrosis could put the body at risk for the inability to cool themselves due to a lack of sweating[2, 3]. Anhidrosis can occur from surgery or trauma, inflammation of the skin, scar formation, or infections[38]. It remains to be researched if these individuals with anhidrosis occur due portal occlusion or if sweat is not secreted to the skin surface[38]. Sweat transported to the surface can irritate the already infected skin in individuals with psoriasis or atopical dermatitis[38]. These individuals experience a burning sensation of the skin on a hot and humid day[38]- suggesting that sweating does occur under the skin lesion[38].

Cystic fibrosis (CF) is an autosomal recessive disorder that alters the way the sweat gland can reabsorption of sweat chloride as well as sweat sodium[39]. Cystic fibrosis genetically alters the cystic fibrosis transmembrane conductance regulator, which makes the sweat duct impermeable to chloride[39]. For instance, an individual with CF will be unable to reabsorb sweat chloride because of the occlusion of the cystic fibrosis transmembrane conductance regulator. The absence of a non-functioning cystic fibrosis transmembrane conductance regulator will limit the amount of sodium reabsorbed as well because the epithelial sodium channel is activated together with the cystic fibrosis transmembrane conductance regulator[39]. This condition will cause an increase of 3-5 times the normal limit of surface sweat sodium and chloride[39].

Conclusion and Future Research

Thermoregulation, as well as sweat testing, are frequently researched. The production of sweat and the end electrolyte concentrations are individualized[1,4,6,7,8-10,25,27,30,36,37]. Each of these studies all examined sweat electrolytes, sweat rate, and sweat collection.

Various methods of sweat methodology are discussed in this literature review. The use of local absorbent patches is the most realistic and practical method to used to collect sweat in a field study[1]. Sweat rate and sweat electrolyte concentration is very individualized, based on individual considerations and heat acclimation[1,4,6,7,8-10,25,27,30,36,37].

There is a gap in literature and research that does not compare sweat electrolyte concentration and sweat rate when performing two different modes of exercise in the same individual. It is understood that there will be a biomechanical difference in comparing two different forms of exercise, but exercise intensity was controlled. For instance, oxygen consumption increases with exercise intensity[12]. Therefore, sweat rate increases with core body temperature, while sweat sodium concentrations increase linearly with sweat rate[12,40].

Chapter two:

Introduction

Thermoregulatory sweating was extensively researched and studied. There are multiple techniques to obtain sweat data using various methods[2]. Understanding what a physically active person loses throughout an exercise bout is critical to understand for dietary supplementation[5].

Temperature regulation is the body's response to thermal stress, by acting in an effector response to maintain core temperature homeostasis[1]. These effector responses are sweating and shivering[1]. A rise in a T_c above 37°C[3] will stimulate sweating, which is regulated by the hypothalamus[1-3,5,6].

Apoeccrine, apocrine, and eccrine are three types of sweat glands that are located all across the body[2,3]. Apoeccrine and apocrine are limited to specific regions on the body (axillae region) and are not responsible for thermoregulatory sweat and only become active until puberty, while eccrine glands are responsible for thermoregulatory sweating[2,3,7].

Eccrine glands are located all over the body, while the distribution of the glands varies across the skin surface[3,7]. The highest density of eccrine sweat glands is on the palms of hands and feet and forehead, following upper limbs, and finally lower limbs and trunk[3,7]. There are approximately 1.6-4.0 million eccrine sweat glands on the human body[2,3,31].

The body losses sodium, potassium, and chloride through eccrine gland sweat [2,4,6,8,11,13,14,16,18,24,27,28,30]. Eccrine glands surrounded by nonmyelinated class C sympathetic postganglionic fibers, which are stimulated by acetylcholine[2,4,6,31]. As acetylcholine is released into the presynaptic terminal, an influx of calcium ions enters the cell and stimulates sodium-potassium pumps to start pumping sodium ions into the gland[6]. Due to osmosis, water follows the sodium into the gland as well[6]. Sodium-potassium pumps actively transport sodium and chloride to the skin surface[6].

Sweat within the sweat gland is primarily isotonic with blood within the gland at 135-145 mmol/L[2,3,6]. Sweat on the skin surface ranges from 10-90 mmol/L[2,5]. As sweat travels up the sweat duct, sweat is passively and actively reabsorbed[2]. Sodium is passively reabsorbed via sodium channels and actively reabsorbed by sodium-potassium pumps[2,24], while chloride ions passively reabsorbed via cystic fibrosis transmembrane conductance[2].

Eccrine glands are scattered all over the body in various densities[3,7]. There are multiple ways to obtain a sweat sample. The gold standard for sweat collection is known as the whole-body washdown technique[14]. This method does not interfere with the natural evaporative process[14]. This method does have a limitation; using the WBW technique can only be performed in a laboratory setting and can only be done on a cycle ergometer. However, there is another method of obtaining sweat samples, which makes it easy to use for collecting data in the field, adhesive sweat patches. The sweat patch technique is ideal for field studies[2]. Before the patch is applied, it is common practice to clean the skin surface before the sweat patch is applied[2]. Cleaning the skin with alcohol, wiping dry, rinsing the skin with deionized water, wiping dry again, and then application of the sweat patch will limit surface contamination in the final sweat sample[2]. Correct anatomical sites must be selected to estimate whole-body electrolyte loss[13]. Previous studies have looked into which anatomical site is an accurate representation of whole-body sweat electrolyte loss. The forehead tends to over-estimate, while the foot, thigh, low back, and forearm tend to have accurately estimate whole-body sweat electrolyte loss[2,3,5].

Sweat rate and sweat electrolytes vary among individuals[2,4,6,14,18,24,27,28,30]. Males have a higher incidence of sweating, thus potentially having a greater secretion rate of sodium[2,4,5,28]. Acclimation also plays a part when assessing sweat rate and sweat electrolytes. Exercising in the heat for an extended period over a few weeks will show physiological changes[30]. A shift in the onset of sweating will occur at a lower T_c[11,18,30] and will increase the reabsorption rate of sweat sodium and chloride[16,30].

Recent investigations of sweat sodium and sweat rate found that there are vast ranges of sweat rate and sweat electrolyte concentration by sport. Mean sweat rates for American football players are 2.14L/h[4]. However, there is a wide range of sweat rate amongst American football players. They are ranging from 1.4 L/h – 2.25 L/h[5]. The ranges in sweat rate can be explained by body surface area to mass ratio[5]. Due to the larger size of the linemen, they will have more glands to produce more sweat when compared to the smaller running backs and receivers[5]. Due to the higher BSA in linemen, they also lose a more considerable amount of sodium through sweating[5]. They lose an average of 12.5 grams of sodium when compared to running backs, who lost an average of 7.5 grams throughout two practices[5].

Investigators have reported sweat rate and sweat sodium losses during training in European football players[16] and endurance athletes[4,8]; however, no data investigates the difference in sweat rate and sweat electrolyte loss in the same individual performing two different modes of exercises. Therefore, the purpose of our study is to investigate sweat electrolyte concentration and sweat rate in triathletes during running and cycling exercising at the same intensity in a thermoneutral environment.

Purpose Statement

The primary purpose of this study is to compare sweat electrolyte concentration and sweat rate in triathletes during running and cycling exercising at the same intensity in a thermoneutral environment.

Research questions

1. Does sweat electrolytes (Na^+, Cl^-, K^+) concentration differ between cycling and running in trained triathletes exercising in a thermoneutral environment?
2. Does sweat electrolyte (Na^+, Cl^-, K^+) concentration and sweat rate differ between sexes in trained triathletes in a thermoneutral environment?
3. Does sweat rate differ between running and biking in a thermoneutral environment?

Null Hypotheses

H_{01}: There will be no difference in sweat electrolyte (Na^+, K^+, Cl^-) concentration in sweat samples collected from trained triatheltes during running or biking at the same exercise intensity

H_{02}: There will be no difference in sweat rate of trained triathletes running or biking at the same exercise intensity

H_{03}: There will be no sex difference in sweat electrolyte concentration (Na^+, K^+, Cl^-) from sweat samples collected from trained triathletes during running and biking

H_{04}: There will be no relation in sweat rate and sex in trained triathletes during running and biking at the same exercise intensity

Chapter three:

Methods

Participants: 20 subjects recruited via previously known contacts through triathlete coaches and individual athletes.

Research design

A randomized cross-over design. The main outcome measures are sweat rate, total sweat losses, sweat electrolyte (Na^+, Cl^-, K^+) composition, and total electrolyte loss. Independent variables were time to sweat patch removal, mode of exercise (running versus cycling) at an RPE of 11-15, and gender. Dependent variable are sweat rate (L/h), sweat loss (L), sweat electrolyte loss (mg/hr), sweat Na^+, K^+, Cl^-, concentration (mmol/l) and sex differences (ht. wt. BSA).

Sweat rate

Total sweat rate was calculated by subtracting the participant's pre-trial nude body weight, post-trial nude body weight, and urine volume. Then add their fluids consumed and then dividing the sum by exercise time.

$$\frac{\{[\text{Pre-body mass (kg)} - \text{Post-body mass (kg)}] - \text{Urine volume (l)} + \text{Fluids consumed (l)}\}}{\text{Total exercise time (hr)}}$$

Sweat electrolyte (Na^+, Cl^-, K^+)

All participants are wearing two adhesive sweat patches during each trial. One patch was placed on the right medial low back 4 centimeters from L_3-L_4 and the other on the right forearm over the brachioradialis region. Each patch will be made of sterile gauze approximately 2.5 x 2.5-cm then cover in a transparent semi-permeable adhesive dressing. Before the application of each sweat patch, each site will be cleaned with an alcohol prep pad, dried with sterile gauze, cleaned with deionized water, and dried a final time with sterile gauze. Each patch is removed with tweezers once becoming saturated with sweat, approximately 30-45 minutes into the exercise bout. Each saturated sweat patch will be placed in a sterile, low retention tube and centrifuged for 4 minutes at 3,000 RMP (Eppendorf, Mini Spin Plus). 50µl of net sweat is pipetted out and diluted with 100µl of diluent. The 150µl net solution was mixed by hand and analyzed by an ion-selective electrode analyzer (Roche, 9180 ion-selective electrolyte analyzer) to determine the amount of sweat electrolytes (Na^+, Cl^-, K^+) in the sweat sample.

<u>*Procedure*</u>

Each subject will complete two days of data collection. Each trial was completed no more than two weeks apart from each other and around the same time of day.

Trail 1: The first trial was randomly selected. Each subject was notified 24 hours prior to which exercise bout they will be performing first. Each subject reported to their training facility to complete their trial. Both trials were conducted indoors in a thermoneutral environment with no convective cooling. Before testing, each subject turned in a 24-hour food log. Upon arrival at their training facility, each subject voided their bladder and gave a nude body weight using a scale. Lastly, two absorbent sweat patches were applied to their right forearm and low back area after a thorough cleaning. Water was available during the trial, for fluid consumption, but the weight of the bottle was taken to track how much fluid they consume for an accurate sweat rate.

The Borg rating of preserved exertion scale is used to control for exercise intensity. A copy of the scale was given to each subject, and their exertion range should fall between 11-15. Perceived exertion was asked at baseline and every 5 minutes into the trail until the trail is complete. After 1-hour of exercise, each subject had their sweat patches removed and placed in two separate low retention tubes, or the sweat patches were removed once they have become saturated with sweat. Subjects were then asked to weight out with final nude body weight.

Trial 2: The second trial was completed within 2 weeks of the first trial. The second trial followed the same instructions from trial 1.

Once both trials were complete, within a 14-day window, the sweat samples, scale, tweezers, deionized water, and urinal were mail immediately to the HEAT Institute located on the West Chester Campus in West Chester, PA.

<u>*Instrumentation*</u>

Borg Scale. All participants received a Borg scale to take RPE every 5 minutes into exercise for each trial.

Sweat rate. Total sweat rate was calculated by subtracting the participant's pre-trial nude body weight, post-trial nude body weight, and urine volume. Then add their fluids consumed and dividing the sum by exercise time.

$$\frac{\{[\text{Pre-body mass (kg)} - \text{Post-body mass (kg)}] - \text{Urine volume (l)} + \text{Fluids consumed (l)}\}}{\text{Total exercise time (hr)}}$$

<u>*Data analysis*</u>

In order to find a relationship between the different modes of exercise, a paired t-test are conducted (running and cycling: sweat rate, sweat loss), and an unpaired t-test are used to assess and compared the tri-athletes demographics (male versus female). Pearson correlations are used to assess strengths between dependent variables. A one-way ANOVA is used to determine the sex differences in total sweat rate, total sweat electrolyte loss (Na^+, Cl^-, K^+)

composition, and total electrolyte (Na^+, Cl^-, K^+) loss by trial. For all tests, a statistical significance level is set at p <.05. All analysis is conducted using VassarStats (2008; Vassar College, Poughkeepsie, NY).

Chapter four:

Results

No difference existed between the experimental trials in the environmental condition's temperature before exercise (T_a= 20.75 °C ± 1.8, $r(38)$=.26, p=0.55) and environmental conditions after exercise (T_a=22.05°C ± 1.3, $r(38)$=.19, p=0.42) or in rating of perceived exertion (RPE = 11.99 ± 2.14, p = .841). A significant relationship is found between trials in relative humidity before (RH= 35.33% ± 8.0, $r(38)$=.09, p= .003) and after (RH= 40.56% ± 5.9, $r(38)$=.09, p= .04).

Sweat rate

No significant difference in SwR (L/hr) were observed during either trial (Bike = 1.12L/hr ± 0.58, Run 1.12L/hr ± .55, $r(38)$=.80, p = 1.00)

Sex by trial

A significant relationship were observed regarding sex. A one-way ANOVA showed a SwR (L/hr) between male and females (Bike males = 1.52 ± .49, Bike females = 0.72 ± .36, Run males = 1.57 ± .35, Run females = 0.67 ± .23, $F_{(3,36)}$ = 11.96, p = <.001).

Sweat Na^+

By trial

No significant difference in $SwtNa^+$ (mmol/l) were observed during either trial (Bike = 59.33 ± 28.64, Run = 62.93 ± 28.90, r=.80, p = .691). No significant difference in $SwTNa^+$ loss (mg/hr) between trials (Bike = 1682.56 ± 1427.67, Run = 1769.29 ± 1429.39, $r(38)$ = .837, p = .850.

Sex by Trial

A significant relationship were observed regarding sex and $SwtNa^+$ (mmol/l). A one-way ANOVA between sex and trial (Bike males = 71.88 ± 32.99, Bike females 46.77 ± 32.52, Run males = 77.23 ± 32.52, Run females 48.63 ± 15.87, $F_{(3,36)}$= 3.65, p= .021). A significant relationship were found between $SwTNa^+$ loss (mg/hr) between sex and trial (Bike male = 2560.95 ± 1498.52, Bike female = 804.177 ± 585.51, Run male = 2792.93 ± 1370.17, Run female = 745.65 ± 327.76, $F_{(3,36)}$ = 10.63, p = <.001).

Sweat Cl^-

By trial

No significant relationship was observed in $SwtCl^-$ (mmol/l) between bike (49.87 ± 26.29) and run (37.83 ± 17.48, $r(38)$=.89, p=.097). No significant relationship is observed in $SwtCl^-$ (mg/hr) between bike (2223.99 ± 1914.38) and run (1649.69 ± 1319, $r(38)$=.90, p=.278).

Sex by trial

Sex differences were compared and significant difference in $SwtCl^-$ (mmol/l) was found between males and females (Bike Males = 63.04 ± 29.30, Bike Females = 36.70 ± 14.66, Run Males = 47.28 ± 19.70, Run Females = 28.39 ± 7.6 $F_{(3,36)}$ = 5.87, p = .002). Additonally, a sex difference was found between $SwtCl^-$ loss (mg/hr) between males and females (Bike Males = 3441.77 ± 1945.51, Bike Females = 1006.22 ± 810.19, Run Males = 2613.88 ± 1231.07, Run Females = 685.50 ± 302.50, $F_{(3,36)}$ = 11.36, p = <.001).

Sweat K^+

By trial

No significant relationship between $SwTK^+$ (mmol/l) between (Bike = 4.79 ± 1.95) and Run = 5.59 ± 2.3, $r(38) = .62$, $p = .235$). A significant relationship between $SwTK^+$ loss (mg/hr) is observed between (Bike = 208.32 ± 125.79) and (Run = 106.11 ± 66.03, $r(38) = .006$, $p = .002$).

Sex by trial

No significant relationship between $SwTK^+$ (mmol/l) between sex was observed (Bike Male = 5.18 ± 2.04, Bike Female = 4.39 ± 1.87, Run Male = 5.66 ± 2.21, Run Female = 5.51 ± 2.52, $F_{(3,36)} = .677$ $p = .571$). However, a significant relation between $SwTK^+$ loss (mg/hr) between sex is observed (Bike Male = 291.29 ± 102.51, Bike Female = 125.34 ± 14.65, Run Male = 70.31 ± 14.65, Run Female = 141.91 ± 78.37, $F_{(3,36)} = 14.59$, $p = <.001$).

Dietary intake salt/ salt loss

By trial

No significant relationship was found between salt intake (mg) between trials (bike = 3649.82 ± 3372.0, run = 3418.99 ± 2740.65, $r = .21$, $p = 0.526$). No significant difference found between salt loss (mg) and trials (bike = 3085.33 ± 1559.09, run = 3484 ± 2786.45, $r = .81$, p = .578). No significant relationship between salt intake and salt loss (mg) in trials ($r = .380$, $p = .811$).

Table 1 Demographics

	Male (10)	Female (10)
Age (yr)	37.5 ± 7.94	43.5 ± 7.50
Height (m)*	1.82 ± 0.04	1.58 ± 0.10
Body mass (kg)*	79.72 ± 6.56	57.73 ± 7.03
BSA (m^2)*	2.00 ± .09	1.59 ± .13
BSA/mass (cm^2/kg)	417.76 ± 34.36	437.19 ± 49.82

*Indicates difference between sexes (P=<.05)

Table 2 Sweat rate and sodium loss

	Male		Female	
	Run	Bike	Run	Bike
Sweat rate(L/hr)†	1.57 ± 0.35	1.52 ± .494	0.67 ± 0.23	0.72 ± 1.08
NaCl loss (mg/L) †	3450.13 ± 1422.36	3828.63 ± 1762.55	2123.87 ± 616.14	2342.03 ± 892.90
NaCl loss (mg/hr) †	5406.81 ± 1954.08	6002.71 ± 3438.11	1432.16 ± 615.95	1810 ± 1393.20

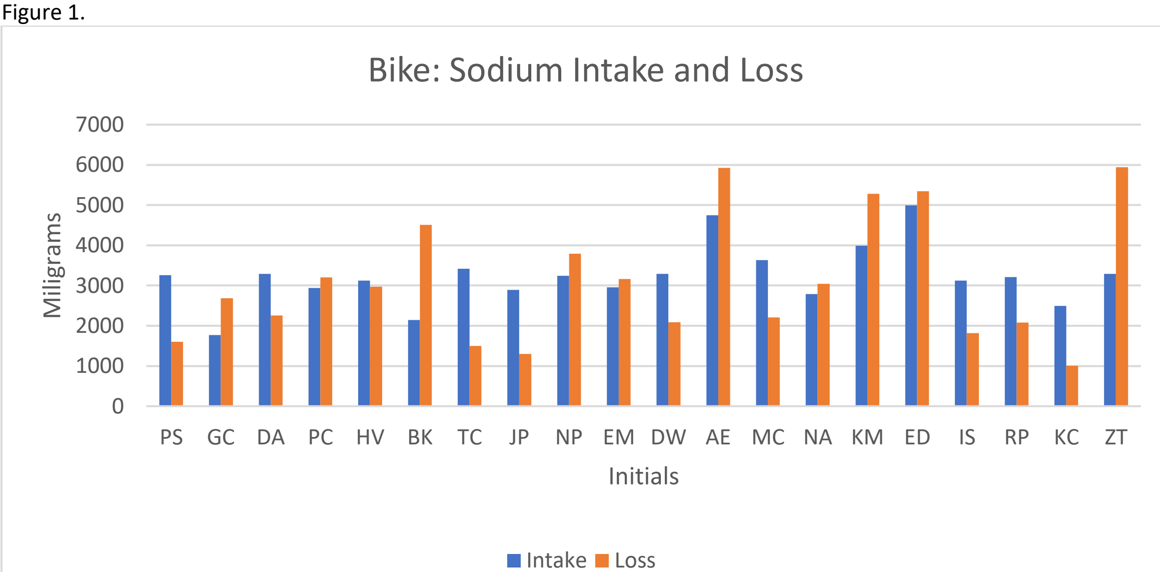
*Indicates difference between run or bike (P=<.05)
†Indicated difference between sex (P=<.05)

Table 3 Dietary recall and salt loss

	Male		Female	
	Run	Bike	Run	Bike
Carbohydrates (g)	269.13 ± 269.13	359.46 ± 182.56	248.98 ± 87.53	279.27 ± 111.167
Fats (g)	120.79 ± 43.68	124.82 ± 38.72	127.02 ± 73.72	113.65 ± 47.52
Protein (g)	133.58 ± 46.14	139.05 ± 38.72	118.6 ± 46.43	109.89 ± 36.72
Salt intake (mg)	3369.67 ± 1351.62	3361.69 ± 1014.66	6333.34 ± 865.46†	3095.87 ± 321.48
Salt loss (mg/hr)†	5406.81 ± 2587.77	5514.91 ± 3793.40	1358.05 ± 662.53	1784.74 ± 1372.65

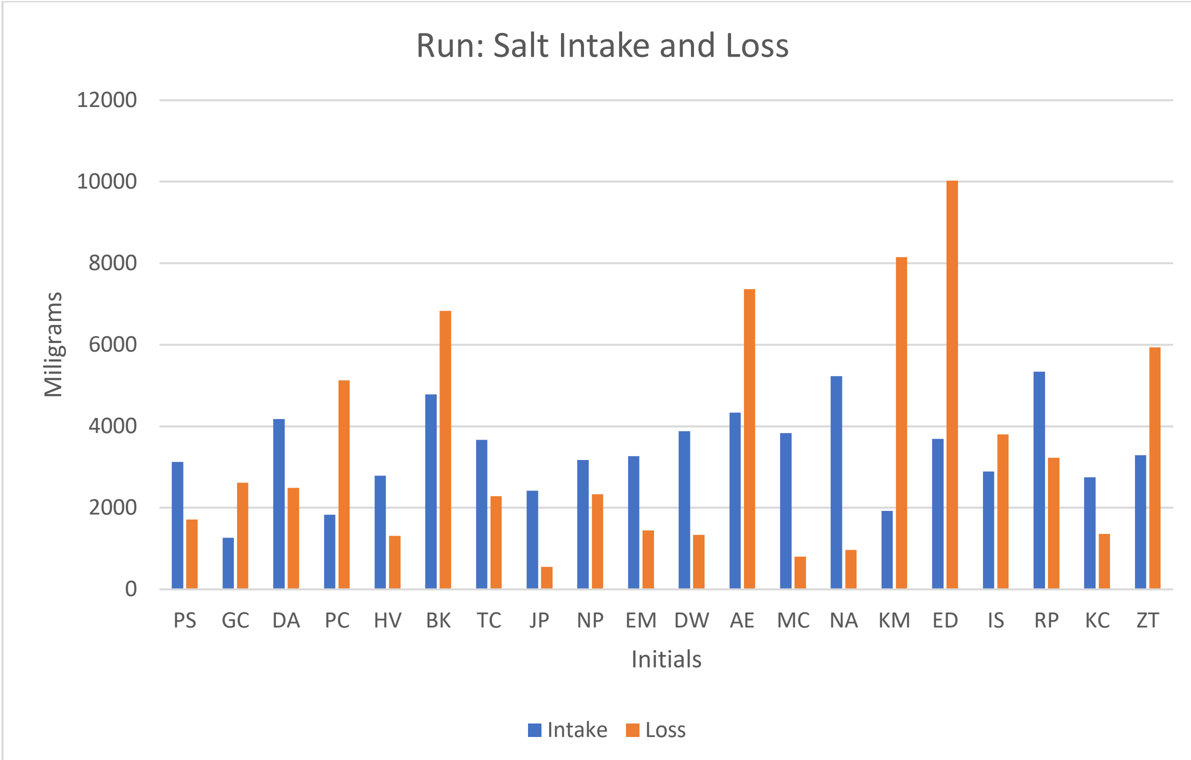
*Indicates difference between run or bike (P=<.05)
†Indicated difference between sex (P=<.05)

Figure 1.



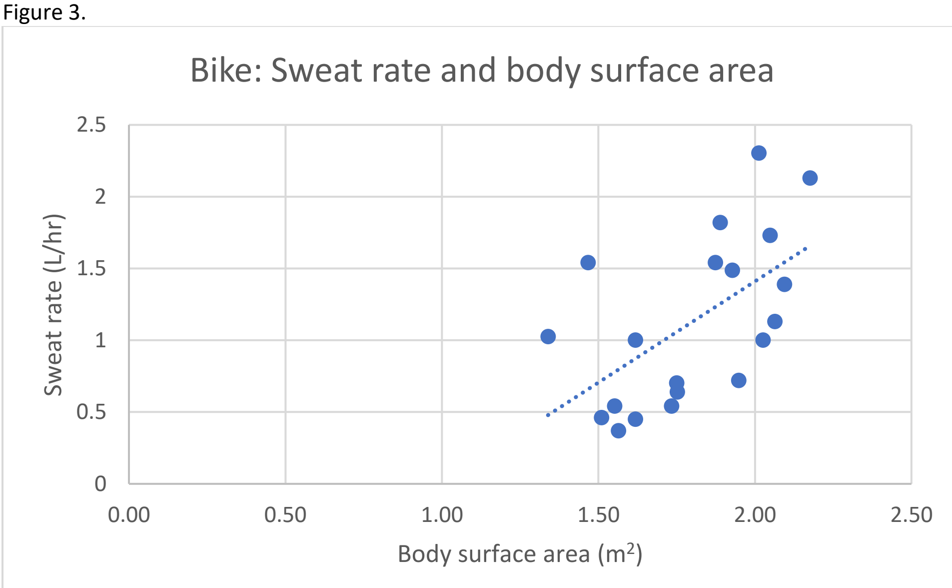
Difference in salt loss (NaCl) and intake. (r = .21, P = .585).

Figure 2.



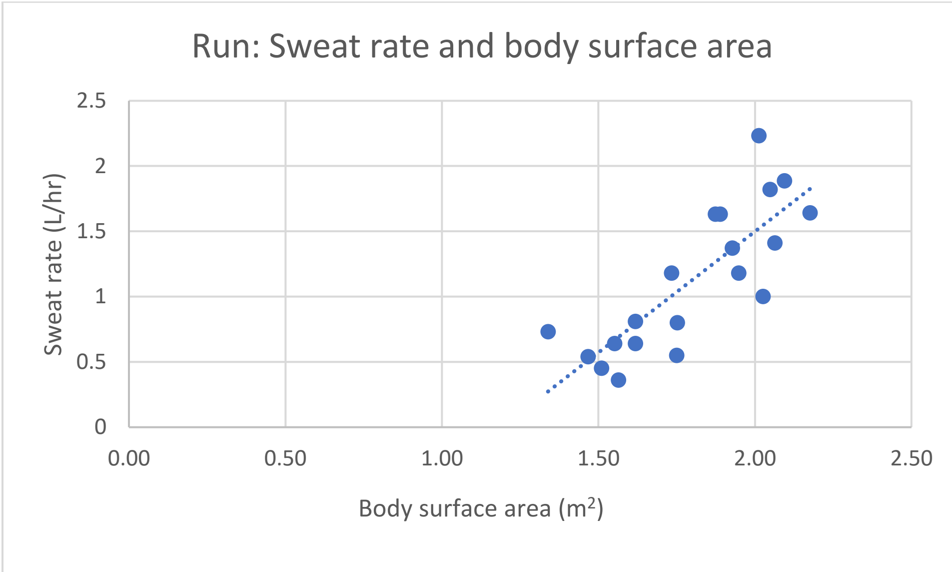
Difference in salt loss (NaCl) and intake. (r = .023, P = .997).

Figure 3.



Sweat rate and body surface area (r = .579, P = <.001)

Figure 4.



Sweat rate and body surface area (r = .812, P = <.001).

Chapter five:

Discussion

The findings of this master's thesis support the theory that sweat electrolyte concentration and sweat rate do not differ between running and cycling in trained triathletes. There is currently no published research regarding the change in sweat composition and sweat rate. Another significant finding of this study is the potential for the body to regulate sweat sodium concentration if the is overloaded with sodium. Secondly, we investigated the sweat rate during run and biking for one hour. To our knowledge, this subject has not been extensively researched. Therefore, we think our findings will serve an essential contribution to the literature.

The primary purpose of our study determined whether sweat electrolyte concentration and sweat rate changed between two separate modes of exercise. The results indicate that sweat electrolyte concentration (Na^+, K^+, Cl^-) does not change for running and biking. Although the sweat electrolyte concentration had a large range between sweat sodium (Run = 1464.57 to 4997.93 mg/l, Bike = 1007.4 to 5938.19 mg/l), the difference in mg/l is not great enough to produce a significant difference in the loss in mg/hr. These results have implications that when calculating overall sweat electrolyte loss for replacement, that during one hour of either exercise, the needs of the replacement needs are the same.

We did not find differences in sweat Na^+, sweat Cl^-, or sweat K^+ concentrations (mmol/l) between the run and bike trials. However, we found significant differences between male and female sweat Na^+ and Cl^- but not in sweat K^+ (Bike Na^+ males = 71.88 ± 32.99, Bike Na^+ females 46.77 ± 32.52, Run Na^+ males = 77.23 ± 32.52, Run Na^+ females 48.63 ± 15.87, Bike Cl^- Males = 63.04 ± 29.30, Bike Cl^- Females = 36.70 ± 14.66, Run Cl^- Males =

47.28 ± 19.70, Run Cl^- Females = 28.39 ± 7.6). We are not surprised by these results because Meyer et al. [30] found similar results. Gender difference does occur because sweat electrolyte transport may respond to hormonal variations[30]. We did not measure hormonal levels in this study.

Exercise intensity, as in metabolic heat production, is directly related to energy expenditure[44]. Our study focused on an RPE rating between 11-15 for both trials. We had no difference between trials (RPE = 11.99 ± 2.14, p = .841). Sweat electrolytes, specifically sodium and chloride, increase with a rise in exercise intensity; this is due to an increased sweat rate, which allows less time for sodium and chloride to be reabsorbed[44].

Total body sweat loss was not significant between trials (Bike = 1.12L/hr ± 0.58, Run = 1.12L/hr ± .55). However, it was statistically significant between males and females (Bike males = 1.52 ± .49, Bike females = 0.72 ± .36, Run males = 1.57 ± .35, Run females = 0.67 ± .23). It is also important to note that there is a significant finding between male and female (table 1) body surface area (male = 2.00 ± .09, female = 1.59 ± .13). Body surface area and sweat rate are highly dependent on one another[31, 41]. Godek et al.[31] and Havenith, G., & van Middendorp[41] found that sweat loss was 50% dependents on body size (BSA) rather than physical fitness. Therefore, the higher the sweat rate, the greater BSA, when compared to individuals with a lower sweat rate, will have a less BSA[31]. Due to the greater the BSA, the greater number of sweat glands will increase the sweat rate[31]. The important point is that males had a higher sweat rate due to the greater BSA (figure 2 and 4). This difference is crucial when considering fluid replacement needs for these athletes.

Another important note from this study is that the 24-hour dietary recall was the same between both trails (figures 1 and 2). Salt intake ranged from 295.2 g to 5338.4 g.

Surprisingly, the underconsumption or overconsumption did not manipulate the sweat electrolyte concentration ($r = .380$). Our results support the finding by Koenders et al.[42] and Konikoff et al.[43] that found no statistical difference between sweat Na^+ and dietary intervention. Surprisingly, the body can to regulate its sweat electrolyte concentration-independent to if there was an over or underabundance of sodium in the blood.

Limitations

The most significant limitation of this study was the inability to track dietary electrolyte consumption. Some participants forgot to keep a food log and had to rely on the memory of everything they ate the day before their trial. The trials used in this study only took a snapshot of what a triathlete may lose during one hour. This study was also conducted during the winter, which will directly affect sweat sodium.

Future research

Since this study only investigated in triathlete biking indoors without any convective cooling, more studies should look at the effect of sweat electrolyte differences between stationary biking and convective biking. Further research should determine if sweat composition will be different at the end of triathlon since triathlons can last (8< hours) when compared to the first hour aiding in the need for electrolyte replacement for prolonged exercise. It is not known if triathletes, which are sodium depleted, will consume the appropriate amount of salt in their regular diet to replace their losses.

Conclusion

From this study, it can be determined that triathletes lose the same amount of fluid and sweat electrolytes during running and biking indoors in a thermal neutral environment. Triathletes who do get their sweat electrolyte losses calculated can use their replacement needs for running and biking. An important finding to recognize because there is a vast range of sodium losses across this cohort. Knowledge of the triathlete's sweat rate and sodium losses is critical for appropriate fluid and electrolyte balance. Given only this study calculated 1 hour for losses, triathletes may lose up to 8 times this amount during a triathlon. It is important for athletes everywhere to become familiar with how much electrolytes they could lose during an exercise bout, and with having that knowledge they can replace accordingly.

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Appendices

Informed Consent

Project Title: A Comparison of Sweat Rate and Sweat Electrolyte Concentration in Tri-Athletes During Running and Cycling

Investigator(s): Daniel Webb; Sandra Fowkes-Godek

Project Summary:

Participation in this research project is voluntary. It is being done by Daniel Webb as part of his Master's Thesis to discover the difference of running versus cycling on sweat sodium during exercise. Your participation will take about 80 minutes you will report to your normal training facility, record all food eaten within 24 hours of trial, record a nude body weight prior to exercise, put on the sweat patches, weigh water bottle, exercise for 60 minutes, remove sweat patches, record a nude body weight after exercise, weigh water bottle. There is minimal risk of possible discomfort may include: I understand that there is little risk of harm to me when I do this study. I understand that if I become dizzy, unsteady, feel sick, or I get too hot, the trial will be stopped. If I experience discomfort, I have the right to stop the study at any time. There is Benefits to you may include: I understand that the study will benefit me by giving me information about my sweat electrolyte for two types of exercise. This information will help me understand my fluid needs for running and biking. Other benefits may include: This research may help people understand how to drink for two different modes of exercise to you as the participant.

The research project is being done by Daniel Webb as part of his Master's Thesis to Determine the effects of running versus cycling on sweat sodium concentration during exercise. If you would like to take part, West Chester University requires that you agree and sign this consent form.

You may ask Daniel Webb any questions to help you understand this study. If you don't want to be a part of this study, it won't affect any services from West Chester University. If you choose to be a part of this study, you have the right to change your mind and stop being a part of the study at any time.

1. **What is the purpose of this study?**

Investigate the effects of running versus cycling on sweat sodium during exercise

2. **If you decide to be a part of this study, you will be asked to do the following:**
    - Before the study begins, I will have finished a medical history form and been accepted by the researchers to be a subject. As a subject in this study, I will report to the training facility on two different occasions. The first time I report, I will be given instructions about the exercise bouts. Two exercise trials will be explained, I will ride a stationary bike or jog on a treadmill at a moderate pace for 60 minutes. These exercise bouts will be done at room temperature. On the morning of the testing, I will eat a regular breakfast like a bagel and a banana. Before the exercise, I will have my body weight measured while wearing compression shorts and a top. I will then have one sweat patch put on my forearm and one on my low back after the areas are cleaned. I will also put a heart rate monitor around my chest and wear a watch that will allow my heart rate to be monitored.
    - During the exercise bouts, my heart rate will be monitored every 5 minutes. At the end of exercise I will remove the sweat patches and get my final body weight.
    - I understand that to be in the study, I will fill out a medical history form. I give my permission to the researchers to perform my sweat testing. All of these instructions will be completely explained to me by the researchers. If I have questions, I can contact Dr. Sandra Fowkes-Godek, PhD, ATC at (610) 436-2342, and Daniel Webb, ATC at (207) 651-3998
    - This study will take about 80 minutes of your time.
3. **Are there any experimental medical treatments?**
    - No
4. **Is there any risk to me?**
    - Possible risks include: I understand that there is little risk of harm to me when I do this study. I understand that if I become dizzy, unsteady, feel sick, or I get too hot, the trial will be stopped.
    - If I become upset and wish to speak with someone, I may speak with Dr. Sandra Fowkes-Godek, PhD, or Daniel Webb, ATC.
    - If I experience discomfort, I have the right to stop at any time.
5. **Is there any benefit to me?**
    - Benefits to you may include: I understand that the study will benefit me by giving me information about my sweat electrolyte concentration for two modes of exercise. This information will help me understand my fluid replacements needs.
    - Other benefits may include: This research may help people understand how to drink for two different types of exercise.
6. **How will you protect my privacy?**

- The session will **not** be recorded.
- Your records will be private. Only Daniel Webb, Sandra Fowkes-Godek and the IRB will have access to your name and responses.
- Your name will **not** be used in any reports.
- Records will be stored:
    i. in a locked cabinet in Sturzebecker Health Sciences Center Room HEAT Institute, which will also be kept locked.
- All documents and information from your study will be kept confidential in accordance with all applicable federal, state, and local laws and regulations. I understand that medical records and data generated by the study may be reviewed by the West Chester University's Human Subjects Review Board. I understand that the results of this study may be published. If any data is published, I understand that I will remain anonymous and not be identified. The only persons with access to the data will be Daniel Webb, ATC and Dr. Sandra Fowkes-Godek, PhD, ATC.
- Records will be destroyed three years after study completion.

7. **Do I get paid to take part in this study?**
    - No
8. **Who do I contact in case of research related injury?**
    - For any questions with this study, contact:
    - **Primary Investigator:** Daniel Webb at 207-651-3998 or dw909225@wcupa.edu
    - **Secondary Investigator:** Sandra Fowkes-Godek at 610-436-2342 or SFowkes-Godek@wcupa.edu
9. **What will you do with my Identifiable Information/Biospecimens?**
    - Once the sweat sample has been collected for the sweat electrolytes. The sample will be disposed of and the identifiable information will be kept locked in a locked cabinet in the HEAT Institute. There will be no future use of your sweat sample.

For any questions about your rights in this research study, contact the ORSP at 610-436-3557.

I, ________________________________ (your name), have read this form and I understand the statements in this form. I know that if I am uncomfortable with this study, I can stop at any time. I know that it is not possible to know all possible risks in a study, and I think that reasonable safety measures have been taken to decrease any risk.

Subject/Participant Signature ________________________________ Date:________________

Witness Signature________________________________ Date:________________

West Chester University Dept. of Sports Medicine Medical History Questionnaire

Name ________________________________ Today's Date ________________

Birth date ______________ Age ______

Height _______ Weight _____

Home Phone _______________________ Email
____

Cell Phone ___________________

This Information will be kept Confidential

Instructions:

Please circle yes or no to each question. If yes, please give dates and details. If you have a question about any of the statements, circle the corresponding number and it will be discussed with you.

Yes No 1. Have you ever passed out or nearly passed out DURING exercise?
Yes No 2. Have you ever passed out or nearly passed our AFTER exercise?
Yes No 3. Have you ever had discomfort, pain, or pressure in your chest during exercise?
Yes No 4. Does your heart race or skip beats during exercise?
Yes No 5. Have you ever experienced excessive, unexplained shortness of breath or fatigue during or after exercise?
Yes No 6. Has a doctor ever told you that you have (check all that apply):

□ High blood pressure □ Heart murmur
□ High cholesterol □ Heart infection

Yes No 7. Has a doctor ever ordered a test for your heart?(ex: ECG,echocardiogram)
Yes No 8. Has anyone in your family died unexpectedly or for no apparent reason?
Yes No 9. Does anyone in your family have a heart problem?
Yes No 10. Has any family member or relative died of a heart problem or sudden death before 50?
Yes No 11. Does anyone in your family have Marfan Syndrome?
Yes No 12. Have you ever experienced epileptic seizure or been informed that you might have epilepsy?
Yes No 13. Have you ever been treated or informed by a medical doctor that you have asthma?
Yes No 14. Do you cough, wheeze, or have difficulty breathing DURING or AFTER exercise?
Yes No 15. Have you ever used an inhaler or taken asthma medications? If yes, give the dates.
Yes No 16. Do you currently use an inhaler or take asthma medication?

Yes No 17. Do you have any current injuries that inhibit your ability to exercise for two

hours? If yes, please explain.

Yes No 18. Are you currently prescribed medications or drugs on a permanent or semi-permanent basis? If so, indicate the name of the drug and indicate why it was prescribed (Ex. Birth control, high blood pressure, epilepsy etc.)

Yes No 19. When exercising for prolonged periods, do you have severe muscle cramps or become ill?

Yes No 20. Have you ever been treated for heat illness?

Yes No 21. Have you been diagnosed with ADD or ADHD? If yes, please list any medications taken for this condition:____

Yes No 22. Have you ever been told you have sickle cell trait or disease? If yes, indicate when:________________

Yes No 23. Has someone in your family ever been diagnosed with sickle cell trait or disease? If yes, which family member:_____________________________

Yes No 24. Have you ever been diagnosed with SIADH (syndrome of Inappropriate Antidiuretic Hormone)? If yes, when:__________________

Yes No 25. Has someone in your family ever been diagnosed with SIADH? If yes, which family member:________________________________

Yes No 26. Are you currently taking any prescriptions or non-prescription (over-the counter) medicines or pills? If yes, please list:____

____

____

____

Yes No 27. Are you taking any supplements (i.e. creatine, muscle milk, etc?) Please list or indicate NONE

____

____

____

____

Yes No 28. Do you have an ongoing medical condition not previously listed on this form? If yes, please list:____

____

I hereby certify that to the best of my knowledge all of the information herein is true and complete.

Volunteer Signature_____________________________________

Date:______________

Volunteer Printed Name_______________________________________

Borgs RPE scale

Rating	Perceived Exertion
6	No exertion
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

WCU Institutional Review Board (IRB)
Technical Review Form-2019

Protocol # ***(IRB office only)*****:**	20191205A	**Review Date:**	12/4/2019
Primary Reviewer Name:	Shannon Grugan	**Secondary Reviewer Name:**	Michael Di Giovine
IRB Application Title:	Comparison of Sweat rate and Sweat Electrolyte Concentration in Tur-athletes During Running and Cycling		
Principal Investigator (PI):	Daniel Webb Sandra Fowkes Godek	**Faculty Sponsor** (if student PI)**:**	Sandra Fowkes Godek

NOTE: Applicant will have 2 weeks to make changes to the IRB Application, per the comments below. Applicant will email the Reviewer and copy IRB@wcupa.edu with completed revisions OR email reviewer and IRB that applicant needs more time to respond, giving a specific completion date. At one month, without an email response from the applicant, the application will be considered withdrawn.

	Included/ Complete	N/A	Missing/ Incomplete	Comments:
I. Project Information				
Date of application	x			
Project period (no more than 1 year)	x			
Review category	x			
Letter of approval from cooperating institution, if applicable		x		
Letter of acknowledgement from internal department/affiliation		x		
Copy of external support proposal		x		
Other		x		
II.A. Summary				
Background with supporting evidence	x			
Objectives/hypotheses	x			
Research design	x			
Other		x		
II.B. Selection of Participants Identified				
Source of participants	x			
Selection criteria (inclusion/exclusion)	x			
Contact method	x			
Approximately how many	x			
Other		x		
II.C Consent Process				
Consent process description	x			
Waiver of consent/justification		x		
Other		x		
II.D Procedure Outlined				
Frequency, duration and location of each procedure	x			
Other		x		
II.E Confidentiality				
Location of signed consent forms	x			
Location of deidentified data	x			
Method of storage (locked &/or password protected)	x			
Names of people with access (specific names spelled out)	x			
Data destruction date (minimum of 3 years)	x			

	Included/ Complete	N/A	Missing/ Incomplete	Comments:
Other	x			
II.F Risks				
Description of known or anticipated risks & how minimizing	x			
Description of side effects, placebos, normal treatment, etc. & how handling		x		
Other		x		
II.G Benefits				
Anticipated benefits	x			
Importance of resulting knowledge	x			
Other		x		
III. Signatures				
Signatures included from PI and co-PIs	x			
IV. Consent Form				
Based upon WCU sample?	x			Some of the headings are different, but all information is there.
Readability (7th/8th grade language)	x			
Summary of study:	x			
Consent is being sought for participation & is voluntary	x			
Purpose, expected duration, & basic procedures	x			
Risks/discomforts	x			
Benefits	x			
Any alternative procedures if applicable	x			
Included the 9 bolded headings?				
Required Items in Consent Form:				
1. Nature and Purpose of the Project (A statement that the study involves research, an explanation of the purposes of the research and the expected duration of the subject's participation, a description of the procedures to be followed, and identification of any procedures which are experimental)	x			
2. Explanation of Procedures (Description of procedures and a statement that participation is voluntary, refusal to participate will involve no penalty or loss of benefits to which the subject is otherwise entitled, and the subject may discontinue participation at any time without penalty or loss of benefits to which the subject is otherwise entitled.	x			
3. Identification Of Any Experimental Medical Treatments Or Procedures (Disclosure of appropriate alternative procedures or courses of treatment, if any, that might be advantageous to the subject)	x			
4. Discomfort and Risks (A description of any reasonably foreseeable risks or discomforts to the subject)	x			
5. Benefits (A description of any benefits to the subject or to others which may reasonably be expected from the research)	x			
6. Confidentiality (A statement describing the extent, if any, to which confidentiality of records identifying the subject will be maintained)	x			
7. Explanation of compensation, if any. (For research involving more than minimal risk, an explanation as to whether any compensation	x			

	Included/ Complete	N/A	Missing/ Incomplete	Comments:
and an explanation as to whether any medical treatments are available if injury occurs and, if so, what they consist of, or where further information may be obtained)				
8. Name of person to contact in case of research-related injury (An explanation of whom to contact for answers to pertinent questions about the research and research subjects' rights, and whom to contact in the event of a research-related injury to the subject)	x			
9. Statement about future use	x			
Withdrawal Notice	x			
Other		x		
OTHER APPENDICES:				
Questionnaires, surveys, etc.	x			
Recruitment materials (scripts, flyers, etc.)	x			
Current certification of *CITI Human Subject Research* online training for PI, co-PI(s), and any research assistant/individual participating in the project (NOTE: training must have been completed no more than three years prior to the application date)	x			

Is the protocol to be returned to the PI for resubmission? _x__ Yes ___ No

This protocol qualifies for which of the following review categories?

___ Exempt __x_ Expedited ___ Full Board Review

____*Limited*

Office of Research and Sponsored Programs | West Chester University | Ehinger Annex
West Chester, PA 19383 | 610-436-3557 | www.wcupa.edu

Protocol ID # 20191205A
This Protocol ID number must be used in all communications about this project with the IRB.

TO: Daniel Webb
Sandra Fowkes-Godek

FROM: Nicole M. Cattano, Ph.D.
Co-Chair, WCU Institutional Review Board (IRB)

DATE: 12/4/2019

Project Title: **Comparison of Sweat rate and Sweat Electrolyte Concentration in Tur-athletes During Running and Cycling**
Date of Approval:

☒**Expedited Approval**

This protocol has been approved under the new updated 45 CFR 46 common rule that went in to effect January 21, 2019. As a result, this project will not require continuing review. Any revisions to this protocol that are needed will require approval by the WCU IRB. Upon completion of the project, you are expected to submit appropriate closure documentation. Please see www.wcupa.edu/research/irb.aspx for more information.

Any adverse reaction by a research subject is to be reported immediately through the Office of Research and Sponsored Programs via email at irb@wcupa.edu.

Signature:

Nicole M. Cattano

Co-Chair of WCU IRB

WCU Institutional Review Board (IRB)
IORG#: IORG0004242
IRB#: IRB00005030
FWA#: FWA00014155

West Chester University is a member of the State System of Higher Education