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Dietary Sodium Intake and Sweat Sodium Losses in Endurance Athletes

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Dietary Sodium Intake Compared to Sweat Sodium Losses in Endurance Athletes

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Abstract

Dietary Sodium Intake Compared to Sodium Losses in Endurance Athletes

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Context: Sweat rate and sodium concentration has been investigated previously for endurance athletes; however, dietary sodium intake has not been researched. Endurance athletes who have high sweat rates may need to supplement sodium in their diet in order to maintain fluid and sodium balance. Objective: To calculate daily sodium intake for cross country runners over three consecutive days of training and compare them to sweat sodium losses during the three training sessions. Design: Observational field study Participants: Ten athletes (age = 20.5 ± 1.51, height = 173.21 ± 12.66 cm, mass = 65.51 ± 10.60kg) participated. Interventions: Sweat rate was calculated by change in body weight adjusted for fluid consumed and length of training. Sterile sweat patches were used to collect sweat samples from the forearm and low back. The patches were removed post training session, placed in sterile tubes and centrifuged. Sweat was analyzed for sodium and chloride by ion-selective electrode. Diets were analyzed using a common nutrition analysis software, ESHA. Main Outcome Measurements: Sweat rate, sweat losses, sweat sodium and chloride concentrations, daily sodium and salt (NaCl) losses, daily dietary sodium intake, calculated NaCl intake, and body mass. Results: On all experimental days, sodium intake exceeded sodium loss**.** Calculated sweat rates displayed variability that ranged from 0.19 – 1.40 $L \cdot hr^{-1}$. Mean sweat sodium concentration was 60.44 ± 27.76 $mmol/L^{-1}$ (3.71 ± 1.88 g) and ranged from 1.4-6.63 grams. Conclusion: Participant body weight remained consistent (day 1= 65.61 ± 10.48 kg, day 2= 65.51 ± 10.60 kg, day 3= 65.70 ± 10.48 kg). All runners' dietary sodium intake was greater than measured sweat sodium losses indicating that

they maintained sodium and fluid balance during these three days without the need for electrolyte replacement.

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Review of Literature

Introduction

The need for fluid replacement during exercise is widely accepted by the physically active population.[1,2] Excessive sweating can not only result in a deficit in total body water content, but large amounts of electrolytes may be lost as well. The act of maintaining proper electrolyte balance to ensure hydration is not well understood.[2,3] Athletes place their body under greater stress compared to the average sedentary individual. As such, athletes cannot address their energy requirements as well as their fluid and electrolyte needs similar to the average person. An athlete who participates in anaerobic, aerobic, or a combination of activities must assess individual needs for nutrients based on training demands.[2,5] Specifically, in terms of salt intake an individual who participates in intense physical activity may need to consume larger amounts of salt compared to the average person.[5,6] An increase in salt intake through planned meals or at practice through appropriate sodium replacement drinks or salty snacks could aid in the avoidance of performance decrements and negative health consequences.[7]

Over the past ten to fifteen years, investigations into the human body's fluid electrolyte balance have shown the need for supplementation of salt (NaCl) in some athletes. [6,7,8,9] This is especially true when ad libitum drinking occurs during prolonged exercise in individuals who have excessive sweat sodium loses.[2,3,5,13] Although, some individuals are able to replace sodium loses in their normal diet, that is not the case for all individuals.[7,8] The active population, particularly competitive athletes participating in strenuous activity for over two hours in demanding environments, may be in a shortage of sodium stores and be unable to effectively maintain fluid electrolyte homeostasis without supplementation in addition to dietary sodium intake. [7,9,10]

Recommended daily allowance of sodium is stated to be less than 2.4 grams of sodium (one teaspoon of salt) per day. The Center for Disease Control states, the majority of Americans consume greater than 3.4 grams per day exceeding their physiological needs. However, these normalized standards may not be prudent guidelines for individuals who loose large amounts of sodium daily.[2,4,7]

Previous research has shown that professional American football players' average sweat rate, sweat sodium concentrations, and sodium loss exceeds the average individual and recommended daily values. In a study by Fowkes Godek et al., American football lineman had higher sweat rates and sweat losses compared with backs.[7] Sweat sodium losses for American football players ranged from 15 $mmol/L^{-1}$ to 99 $mmol/L^{-1}$.[7] Range of sodium loss per day was 2.3 to 30 g/d.[7] These results provide evidence for sweat rate and sweat concentration variability along with evidence for athletes exceeding recommended daily values.[7]

Similar to American football players who in the past have participated in multiple greater than two hour preseason practice sessions a day, endurance athletes also easily exceed two hours of intense training a day.[5,9]

Table Salt: Sodium Chloride

Table salt (NaCl) is a combination of sodium (40%) and chloride (60%). Salt can be ingested by means of food, drink, or supplements, and is excreted from the body through sweat, urination, and feces (small percentage). Salt falls into the essential nutrient category, as it cannot be made in one's own body. In order to maintain proper fluid homeostasis between intracellular and extracellular fluid compartments, one must actively work to replenish salt lost if those losses are extreme.

Sodium is an electrolyte that is usually lost in greatest quantity.[11] Sodium has the most significant impact on body fluid balance, with effects on fluid retention and plasma volume maintenance.[11] The purpose of sodium in the body is to ensure that fluid balance is maintained between the intracellular and extracellular fluid compartments. The average adult male consists of 60% water, whereas the average female body is made up of approximately 55% water. Two-thirds of total body water is the intracellular fluid, while one-third of total body water is extracellular fluid. Within the extracellular compartment, 75% is interstitial fluid and 25% is intravascular water (plasma). When fluid is lost due to sweating, the osmotic effect allows the sodium in the extracellular space to draw fluid from the intracellular space, thus maintaining fluid homeostasis.[2,4] Maintaining fluid balance is essential for intracellular osmolality, nerve conduction, muscle contraction, and normal renal function.[2]

Total body sodium balance is required in order to maintain proper serum levels of aldosterone and vasopressin, as well as naturetic peptides. This hormone balance assists with homeostasis of plasma volume, sodium concentration, osmolality, and appropriate urine conservation and output of both water and sodium.[2] For example, consumption of excess water or hypotonic fluids leads to decreases in plasma sodium concentration, subsequently causing a decline in aldosterone and vasopressin secretion.[2] As a result urine is produced and sodium is excreted. Conversely, the ingestion of sodium maintains vasopressin levels and averts a diuretic outcome.

In the case that sodium levels become too high vasopressin is secreted by the pituitary gland, causing the thirst response which should stimulate fluid intake. Additionally, aldosterone is released by the adrenal cortex which causes the kidneys to conserve sodium. The negative consequences of sodium retention include high blood pressure, kidney stones, and cardiovascular disease. Adversely, inadequate amounts of sodium can lead to hyponatremia, muscle cramps, heat illness, dizziness, seizures and decrease in exercise performance.[2,4,6,12,13] These potential consequences of either hyper or hyponatremia illustrate the importance of maintaining appropriate fluid and electrolyte balance. Sweat rate and sodium concentrations can assist in appropriate fluid and electrolyte replacement.[14]

Maughan et al., compared fluid and electrolyte retention for three groups, glu-electrolyte drink, glu-electrolyte drink + meal, and water + meal.[8] A significant finding was the retention of Na^+ in both groups containing a meal ($p < 0.05$). The results showed addition of electrolytes to the ingested fluid is not necessary if solid food with appropriate amounts of Na^+ is consumed together with water. Although, in specific instances where eating a full meal is not ideal, addition of Na^+ to drink may be essential for maintenance of fluid balance.[8] The amount of fluid retained was directly proportional to the amount of sodium consumed.[8]

This displays supportive evidence that sufficient hydration is only achieved if the sodium lost in sweat is replaced in addition to fluids.[1,3,5,8] Some means to increase sodium intake include putting table salt on foods, adding salt to sports drink, and taking salt tablets.[1,4,5]

A analysis of 506 athletes determined sweat Na^+ concentrations to range from 13 to 105 $mmol/L^{-1}$.[11,14] The variability between sports and also the large ranges within a sport suggest individual variations of sweat concentration, is 38–53 $mmol/L^{-1}$ in football, 20–62 $mmol/L^{-1}$ in soccer, 43–65 $mmol/L^{-1}$ in swimming, 34–38 $mmol/L^{-1}$ in handball, 54–73 $mmol/L^{-1}$ in ice hockey, 17–73 $mmol/L^{-1}$ in marathon, and 46–48 $mmol/L^{-1}$ in triathlon .[14]

Fluid Replacement

The human body fosters an internal mechanism to prompt drinking. This physiologically driven thirst drive, or the “deep seated feeling of desire for water” is the body’s tool to avoid dehydration or hypohydration, and maintain plasma osmolality and volume.[10] The practice of ad libitum drinking, or more specifically, drinking according to thirst, should be encouraged by health care professionals and sport medicine practitioners when educating athletes.[10]

Fluid replacement of hypotonic solutions will not address sodium depletion or aid in a hyponatremic incident.[2,5,10] The need for appropriate fluid replacement when one is exercising and sweating has become common knowledge and is well practiced. In some cases, the practice of over-drinking has become problematic, particularly in the endurance athlete population.[15, 16] However, the need for appropriate salt replacement due to large sweat electrolyte losses is not commonly addressed.[2,17] The recommended daily allowance of sodium is approximately 2.4 g of sodium, or 1 tsp of salt (NaCl) per day. The average person living in the United States has a dietary sodium intake of approximately 6-8g per day. Therefore, many athletes will have enough sodium stores in their body to function without supplementation. Be that as it may, it is known that considerable sodium and water losses can occur, particularly in athletes known to be heavy salty sweaters, especially when exercise exceeds two hours.[2,6,7]

Individuals with larger surface area generally have a greater number of sweat glands or glands that are larger in diameter.[18] Therefore, they may be disadvantaged in terms of gross sweat losses and adequate fluid replacement.[5,18] However, individual sweat rates vary depending on ambient temperature, humidity, air movement, exercise intensity, insulating clothing or equipment, and body size.[5]

During a moderate workout the average person sweats 0.8 - 1.5 L/h.[1] Maughan et al., investigated male soccer players and found sweat rate ranges from .99 to 1.93 L/h. [19] Although similar to the average person's sweat rate Maughan offers more evidence to support high sweat rates in athletes and variability among individuals.[19] Fowkes Godek et al., reported that the sweat rates of investigated runners participating in preseason training was 1.77 L/h, which was very similar to a previous study by Millard Stafford et al who determined sweat rate of runners during a 40km run to be 1.71 L/h.[5] Importantly, the range of sweat rates in the runners studied by Fowkes Godek et al was 1.04 L/hr to 2.49L/hr, highlighting the large individual variability that is commonly seen even in athletes who are relatively homogenous in size.[5] This was compared to the sweat rates in the cohort of collegiate football players who ranged from 1.10L/hr to 3.6L/hr while practicing in hot and humid conditions.[5] Broad et al., identified soccer players in competition in the heat to have a sweat rate range from 0.99 L/h to 1.21 L/h and basketball players participating indoors to have a sweat rate range of 1.31 L/h to 1.60 L/h.[5,20] Variation exists not only between sport but also within players of the same sport.

Average sweat rate loss in Fowkes Godek et al for American football players was 2.1 L/h including half of the participants losing 2.25 L/h and three players losing greater than 3.0 L/h in multiple occasions.[5] The American football players had high sweat rate and multiple football players' sweat rates exceeded 3.0 L/h due to a combination of body mass, body surface area, and equipment.[5] Fowkes Godek et al then adjusted for body surface area which negated the significant finding between football players and cross country runners, drawing the conclusion that body size contributes to least 50% of sweat loss.[5] Data from these studies of the sweat rates of different athletes indicates that sport variety and body size play a role in determining fluid and electrolyte losses and therefore the individual replacement needs.[5,20]

Continuing this line of research, Fowkes Godek et al., studied the sweat rate and sweat sodium concentration of professional football players, making comparisons between different playing positions.[6] Once again, the results displayed higher rates of sweating in linemen who had a significantly larger body mass and body surface area compared to smaller players such as running backs, defensive backs and wide receivers.[6] The average sodium lost for a professional football lineman was 4.2 g for 90 minutes (single practice) with the highest losses greater than 10g.[6,7] In a nutrient intake study for National Collegiate Athletic Association Division I athletes researchers stated that male athletes had an average of 2.94 g of sodium per day.[6] That dietary intake of sodium would be inadequate for professional football players losing upwards of 4.2g of sodium as shown by Fowkes Godek et al., who had less than 5% of players loss less than 3 g of sodium per day. [7] Confirming the need for individualized sodium recommendations based on individual sodium losses per training session and subsequently, per day for American football players who are heavy salty sweaters.

Sweat

Sweat glands are used to regulate body temperature by secreting sweat droplets, composed of nearly all water, onto the skin. These sweat droplets are then evaporated, cooling the skin surface area which maintains a thermal gradient between the body core and the environment. Sweat glands also excrete waste such as urea and lactate from the body.[21] In addition to water components, sweat includes over 40 compounds, most recognizable being sodium and chloride, as well as small amounts of potassium, magnesium.[21] Training causes sweat gland hypertrophy and therefore increases the amount of sweat per gland produced.[22] As sweat rate increases sodium concentration along with other components also increase.[22,23] Factors that can influence sodium excretion through sweat are environmental conditions, heat acclimatization, intensity and duration of exercise, clothing and equipment, and hydration state.[2,21] Sodium losses can be three times higher in high compared to low intensity training.[24] High levels of sweat do not allows for sufficient time for reabsorption which can be a result of higher concentrations of sodium with increased sweat rates.[24] Sweat rate and sweat composition are variable and individualized among people.[2,5,10] Individual variability of sodium losses across athletes have been estimated from 600mg to 6000 mg.[24] Due to individualization of both sweat rate and sweat sodium concentration there should not be a universal guideline for fluid and electrolyte replacement that applies to everyone.[2,22]

In most cases athletes are able to replenish fluid and electrolyte losses with the average western diet.[1] On the other hand, if athletes are participating in a hot humid environments, are practicing for multiple sessions in a single day, or exhibit large sweat rate or sweat salt concentration it can be concluded that fluid-electrolyte loses will be greater than daily dietary intake.[21]

From a clinical perspective it can be difficult to assess an individual's electrolyte balance as blood samples would need to be analyzed for sodium concentration. Accurate measurements of sweat rate can be obtained, however this challenge requires knowing the change in body mass as well as the volume of fluid consumed and urine produced during the exercise bout. In order to calculate dietary sodium needs, an analysis of sweat samples collected from the athlete during exercise would be required. Then, accurate calculations of sodium losses could be made, resulting in a better understanding of an athlete’s whole body fluid and electrolyte balance.[1,8] Ultimately, due to the individuality of sweat rate and sweat electrolyte concentration, a customized fluid and electrolyte replacement plan might be necessary.[6,9,10,25]

There are many approaches dating back to the 1930s utilized to complete sweat collection. Some of these methods include local patch collection, filter paper, gauze absorption, skin scraping, multisite pipette suction, sweat gland cannulation, rubber glove and arm bag collection, and whole body wash-down technique.[11] The gold standard and method choice, as described by Sheriffs and Maughan, is the whole-body wash-down technique.[26]

The universal methods for gathering sweat electrolyte concentrations are the whole body washdown or regional skin surface collections.[27] The whole body washdown is considered most accurate because all sweat runoff is accounted for and there is no interference to the evaporative process of sweating. However, the whole body washdown requires participants to be in a laboratory setting. The whole body washdown requires, clothing to be washed with water only, entire body washed and scrubbed with water only, exercise while sweat droplets are blotted with cleaned (water only washed) towel, sweaty clothing is collected, post exercise participant is "rinsed" with 2 gallons of deionized water on top of a clean tarp, all fluid is captured and towel and clothing fluid is added together. The investigator then collects a sample of the fluid gathered in a clean pipetted to then be analyzed.[27]

It is understood that regional skin surface collections overestimate Na+. [27] However, regional sweat patches are practical for field and treadmill studies. Single site patches can be used if access to skin is not possible. Multiple site collection can be used to estimate whole body sweat electrolyte losses using weighted equations for local sites. It should be understood that regional skin surface collections are limited due to regional variations in sweat rate and suppressing evaporation of sweat with occlusive dressing.[27] Local collections are completed using sterile gauze patches applied to specific locations (forearm, low back, chest, calf) after the skin has been cleansed.[6] The patches are removed from participants within 30-60 minutes of the initiation of exercise, placed in sterile tubes, centrifuged, and analyzed by either flame photometry, or more recently via ion-selective electodes.[6,21,27]

It is important that sweat electrolyte concentrations are accurate; it is impractical to complete field study's utilizing whole body rinse technique.[27] Comparing whole body rinse and regional patch collection all regional patch sites were highly significantly correlated with whole body washdown for sweat Na+.[27] These results support the practice of collecting sweat from regional patch sites to estimate whole body electrolyte loss, when utilizing local site weighted equations for estimation.[27]

Sweat volume is calculated by calculating the body weight change during exercise. This is most easily done by having the individual void their bladder, weigh either nude or dressed in minimal dry clothing, exercise for one hour, and then weigh out again either nude or wearing minimal dry clothing. If there is fluid consumed or urine produced during exercise then that must also be measured allowing sweat rate to be calculated as: body weight difference (kg) + fluid intake (L) - urine volume (L) divided by the exercise time in hours.

Dietary Intake Recording

A daily dietary analysis involves awareness and tracking of an individual's food and fluid consumption with exact portions. Water content in food can be estimated to be 20% of volume.[1] As it would be inconvenient and difficult for one to weigh their food, dehydrate until dried, and then subtract weight. It has been configured that 1-gram weight equals 1 mL of water for each food at each meal. In order to accurately calculate fluid and electrolyte intake, a computer software system is necessary to analyze all dietary intake. Following daily input of food and fluids the software will provide kilocalories, grams of carbohydrates, sugars, fat, protein, amino acids, as well as the milligrams of sodium, potassium, chloride, magnesium, and other minerals.[7] It is highly recommended the individual provide as much information as possible regarding brand name, restaurant name, preparation type, and quantity based on a specific proportion sheet determined by the primary investigator. The equation used to configure sodium electrolyte balance is (dietary intake) - (content of urine + feces + sweat). Fecal sodium and urine is considered minor compared to sweat loses, therefore, it is not necessary to include it in the analysis.

Differences in dietary sodium could cause differences in sweat sodium levels.[23] The research Eichner shows highlighting the importance of a high sodium diet during intense activity in hot environments could prevent athletes from muscle cramping (exercise associated muscle cramps), or adverse effects of sodium depletion such as the inability to maintain body weight.[23] Lara et al., studied 157 marathon runners to determine interindividual variability in sweat electrolyte concentration.[28] They found that sweat sodium losses cannot be estimated based on individual characteristics, sweat rate and sweat electrolyte concentration is the best way to determine accurate sodium intake.[28]

A survey of 60 female athletes across all three NCAA Divisions investigated cross-country runners knowledge of nutrition.[29] Subjects who had completed a nutrition course had higher scores. The top four sources of information about nutrition were, magazines, parents, coaches, and teammates, with less then half of surveyors reporting a physician as a source for nutrition information. However, 83% agreed knowledge of nutrition does affect eating and drinking and 91.7% agree or strongly agree that learning facts about nutrition is the best way to achieve favorable changes in habits.[29] Education about dietary intake of sodium needs to be addressed with athletes by health care professionals, including athletic trainers who have the opportunity to serve as the first line of defense.[29]

A survey completed on male and female athletes showed males to be more likely to exceed dietary sodium needs, average sodium intake males 2942 ± 1319 mg and females 2689 ± 1021 mg. An indication of greater sodium intake in males could be that male collegiate athletes are more likely to eat out and that overall meals eaten out are higher in sodium, fat, saturated fat, and cholerterol.[30]

Exercise Associated Hyponatremia

Exercise associated hyponatremia (EAH) can occur during or up to 24 hours post activity.[10] EAH, first described in 1981 by Tim Noakes, is the clinical illness that occurs when an individual has low serum levels below 135 mmol/L^{-1}.[2,4,16,31,] Clinical confirmation of exercise associated hyponatremia is a spot urine sodium concentration below 30 mmol/L^{-1}.[2,4] Possible causes of exercise associated hyponatremia could be excessive sodium loss from sweating, ingestion of low-sodium fluids and solid foods during exercise, overload of the extracellular fluids by excessive fluid intake, impairment of renal function, failure to suppress antidiuretic hormone secretion, and the use of medications, such as nonsteroidal anti-inflammatory drugs.[32] These can result from loss of sodium, excess water, or both.[16] However, in most clinical situations the most common cause is excess total body water as a result of over-drinking before, during or after exercise.[10,16,28,]

Exercise associated hyponatremia is most commonly seen in endurance athletes who participate in intense activity greater than two hours, in a stressful environment, with overconsumption of fluids.[10,12,16] EAH can be asymptomatic or symptomatic, but in most cases asymptomatic situations could go unrecognized unless athletes are currently involved in research where serum sodium is known.[10] In mild cases of EAH the individual will display symptoms of headache, vomiting, swollen hands and feet, restlessness, confusion, wheezy breathing, and fatigue.[33] However without intervention, symptoms can quickly lead to seizure, coma, brainstem herniation, respiratory arrest, cerebral edema, pulmonary edema, and death.[33] Where cases of

EAH become fatal, the individual generally succumbs to cerebral edema and is termed exercise associated hyponatremic encephalopathy or EAHE.[33]

An individual's risk of a severe or even fatal episode increases the lower the serum sodium levels fall, and with a longer length of time that the individual is hyponatremic and goes untreated.[12] Although individuals can exhibit mild symptoms with serum sodium less than 135mmol/L^{-1}, most people with EAH do not have more severe symptoms until sodium levels drop below 130 mmol/L^{-1}.[10] Documented activities where individuals have experienced symptomatic exercise associated hyponatremia include; endurance competitions (marathon, canoe race, ultra-marathon, triathlon, swimming), hiking, military exercises, police training, American football, fraternity hazing, bikram yoga, and lawn bowling.[10] The American College of Sports Medicine states endurance athletes should restore and replenish fluid and sodium loss during exercise.[32] This is done by relying on ad libitum drinking and ingestion of sodium-containing sport drink or by consuming solid foods containing sodium.[32] The 2017 NATA position statement takes a similar stance on EAH, promoting ad libitum fluid consumption and the ingestion of sodium containing food and fluid.[34] However, the 2015 3rd International Consensus Statement on EAH strongly recommends that athletes drink according to their thirst mechanism.[10] An important distinction between drinking ad libitum (whenever you want) and drinking to thirst (when there is a deep-seated desire for water) should be made because many of not most athletes are taught to drink more frequently than their thirst mechanism dictates. [10, 34] The authors of the 3rd international consensus statement clearly promote drinking to thirst as the safest way to avoid both excessive dehydration and the development of EAH.[10]

Acclimatization

The most current research is clear that acclimatization is necessary when beginning activity in a hot and humid environments.[33] Acclimatization results first in increases in plasma volume which results in a decrease in maximal core temperatures reached during exercise.[33] These adaptations are generally complete within the first 7 – 10 days. Additional changes include an earlier onset of sweating, sweating on a greater portion of the body, lower skin temperatures and a decrease in sweat electrolyte concentration. As a consequence, athletes will have lower heart rates and ratings of perceived exertion.[13] These adaptations over time assist with an athletes ability to tolerate exercising in hot, humid, environments.[13,33]

Acclimatization is necessary in order to avoid adverse effects of heat illness, and in particular exertional heat stroke. Throughout the process of acclimatization an individuals' negative side effects to intensity, duration, and frequency of exercise could be affected.[23] Once fully acclimatized to an environment (between days 7-14), thermoregulatory adaptations including any sweat sodium alterations level off.[23]

After acclimatization, sweat glands become more responsive to aldosterone compared to initial days of acclimatization. Eichner documented that 10 subjects exercised in the heat for 10 days and reported that sweat sodium levels declined causing an increase in aldosterone release and therefore increase in sodium retention.[23] Following acclimatization aldosterone can be more effective and appropriately utilized in its role in sweat sodium levels.[23] In order to maintain or even increase extracellular fluid volume aldosterone increases sodium retention.[23] The human body takes time to adapt and acclimatize to hot and humid environments. Characteristics such as genetics, dietary intake, and environmental factors can affect athletic performance.[23]

Electrolyte supplementation maybe necessary for tennis athletes in warm environments following proper acclimitization.[25] It has been shown that individual tennis athletes can incur considerable sodium losses due to excessive sweating as a result of multiple matches played a day in warm humid environments.[25] Adverse effects of fluid electrolyte balance can be avoided if proper preventative measures are taken. Including but not limited to, best practice for acclimation, adequate dietary sodium intake, and drinking to thirst.[25] Following governing bodies, for example, the National Athletic Trainer's Association guidelines for acclimatization is necessary to best avoid unfavorable effects of non-acclimatized participation in activity.

Exercise Associated Muscle Cramps

Heat illness is an umbrella term which generally include exercised associated heat cramps, heat syncope, heat exhaustion, heat stroke or any other disorder caused by environmental exposure to heat. Evaporation of sweat is the primary avenue of heat loss during exercise. Sweat is used as a main source of thermoregulation. When exercising muscles contract and produce body heat therefore increasing an individuals' overall body temperature. Heat is transferred from the body to sweat on the surface of the skin.[21]

Skeletal muscle cramps during or after exercise are common occurrences even in the most fit athletes.[9] At onset muscle cramps may be small "twitches" in a single muscle, and if gone unnoticed or ignored progression to larger spasms of groups of muscles and intense pain could occur.[25] Exercise associated muscle cramps do not necessarily occur in hot environments, they are can be an outcome of excessive sweating and large sweat electrolyte losses.[35] Sweat rate is increased in hot environments however, intensity, duration, and type of exercise can also cause increase sweat rates without hot humid environments. Extreme sweating in addition to low dietary sodium intake can lead to contraction of the interstitial fluid compartment (resulting from inadequate fluid electrolyte balance) causing widespread muscle cramping.[35]

Factors that cause exercise associated heat cramps include sweat rate, sweat sodium concentration, and dietary intake of sodium.[35] Bergeron states that adequate consumption of salt and fluid can decrease exercise associated heat cramps in tennis players.[23] In the study completed by Bergeron tennis players prone to heats cramps had sweat rates that range from 1.79 - 3.41 L/h, sweat sodium concentrations from 23.0 - 83.0 mmol/L^{-1}, and sodium loss from 1.375 - 4.770 g/h.[2] All results above are greater than "normal" values for the average individual and therefore cannot follow daily recommended values. Case studies have shown that reduction and possible elimination of cramping in tennis players resulted from increasing dietary salt, consuming beverages containing salt, and remaining hydrated.

Tennis athletes as well as all athletes who sweat heavily and participate in multiple competitions in hot humid environments put themselves at risk if the develop sodium deficits due to insufficient dietary intake for their individual needs.[5,7,23,35] Accurate individual hydration to thirst and appropriate sodium replacement can be effective prevention for decreased chances of exercise associated muscle cramps for a tennis players and heavy salty sweaters.[7,8]

Clinical Relevance and Future Research

Further research is necessary in terms of individualized fluid and electrolyte maintenance for physically active individuals. Individual mass, type of activity, duration, intensity, frequency, environment, equipment, and dietary intake, and all encompass characteristics that could affect individual sweat rate and electrolyte losses. The intensity and duration of endurance athlete training session will yield larger sweat rates and sodium losses. The stress placed on an endurance athlete during a training session exceeding two hours requires their body to rely on sodium stores. Similar to the concept that one does not "hydrate anticipated water loss prior to exercise" pre-training meals are often not sufficient methods for maintaining electrolyte balance during training. In addition, replacement post activity may be too late and negative health side effects of sodium depletion may already occur. Salt tablets, salt in sports drinks, and salty snacks are an effective way to maintain fluid electrolyte balances when training.[8]

Individualized knowledge of sweat rate and electrolyte losses are important in order to ensure optimal athletic performance. There is sufficient evidence to state sodium recommendations cannot be generalized. Sweat rate and sweat sodium variability has been shown among American football players.[3] Sweat rate was higher in American football lineman (2.4 ± 0.52 L/h) than in backs (1.4 ± .66 L/h). The sweat rate range 0.52 (wide receiver) to 3.3 L/h (offensive guard) showed obvious variability.[3] In addition, most runners presented sweat sodium concentrations below 60 mmol/L^{-1}. However, 20 % of marathon runners presented with high sweat salt losses greater than 60 mmol/L^{-1}.[28]

Safety concerns arise when widespread guidelines are set for people, specifically athletes who participate in activity that demands are dissimilar.

It will remain a challenge for any athletes participating in sessions exceeding two hours to maintain electrolyte and fluid balance.[6] Increased education about hydration and electrolyte imbalance for athletes and proper diagnosis and recognition by clinicians is necessary in avoiding adverse effects of excessive sodium losses leading to sodium depletion. Similarly, education about EAH and the negative effects on health and performance in those who over-drink before, during or after exercise is also paramount. Understanding individual sweat rate, sweat sodium concentration, drinking behaviors as well as normal daily dietary intake of sodium are important to all athletes including those who train and compete in endurance events.

Body of Thesis

Introduction

Previous investigations into the human body's fluid electrolyte balance have shown the need for supplementation of salt (NaCl) when drinking to thirst occurs during prolonged exercise in individuals who have excessive sweat sodium loses.[1,2,3] The act of fluid replacement during exercise is widely accepted by the physically active population.[1,2] In some individuals, excessive sweating not only results in a deficit in body fluid but electrolytes as well. Although, some people are able to replace sodium loses in their normal diet, that is not the case for all.[2,25] The active population, particularly competitive athletes participating in strenuous activity for over two hours in demanding environments may not consume enough sodium to effectively maintain fluid electrolyte homeostasis without supplementation or increases in dietary sodium.[3]

The recommended daily allowance of sodium is approximately 2.4 g per day.[2] The average person living in the United States has a dietary sodium intake of 6-8 g per day. Therefore, many athletes will have enough sodium in their body to function without supplementation. Be that as it may, it is known that considerable sodium and fluid losses can occur during exercise that extends greater than two hours in athletes who are heavy salty sweaters.[2,6,10] More specifically, these are individuals who not only have a high sweat rate per hour of exercise, but who also have sweat that contains a high concentration of sweat sodium and chloride. Due to individualization of both sweat rate and sweat sodium concentration there can be no universal guideline for fluid and electrolyte replacement that applies to everyone.[2,10,28]

During a moderate workout the average person sweats 0.8 - 1.5 L/h.[1] Male soccer players sweat rate ranges from .99 to 1.93 L/h and sweat sodium concentration from 15.5 to 66.3 $mmol/L^{-1}$.[8] Although only moderately higher in comparison to the average person's sweat rate

Shirreff et al., states there is variability among individuals within the same sport.[26] Previous research has been conducted to confirm that professional American football players' average sweat rate exceeds that of the average individual. Fowkes et al., states sweat rates of American football players average 2.14 L/h with a sweat range of 1.1 to 3.6 L/h and daily sweat loss of 9.4 L.[5] When grouped by playing position (ranging from smaller backs to large linemen), American football players have a sodium loss range of 7.5 ± 3.9 to 12.5 ± 7.8 g, much greater than the recommended daily allowance of 2.4 g of sodium per day.[5] In addition, Broad et al., stated that soccer players, during a competition played in heat, had a sweat rate range from 1.2 - 1.67 L/h, whereas basketball players participating indoors had an average sweat rate of 1.6 L/h.[5] This clearly indicates that there are differences in sweat rate and sodium concentration when comparing sports. In addition, large ranges in both sweat rate and sweat sodium concentration occur within each sport, with significant variability from one player to the next.

An analysis of 506 athletes determined sweat Na+ concentrations to range from 13 to 105 mmol/L^{-1}.[11,14] The variability between sports and also the large ranges within a sport suggest individual variations of sweat concentration, 20–62 mmol/L^{-1} in soccer, 54–73 mmol/L^{-1} in ice hockey, 17–73 mmol/L^{-1} in marathon running.[14] In a study by Fowkes Godek et al., American football players ranged from 15 mmol/L^{-1} to 99 mmol/L^{-1} .[7] In addition, most runners presented sweat sodium concentrations below 60 mmol/L^{-1}. However, 20 % of marathon runners presented with high sweat sodium losses greater than 60 mmol/L^{-1}.[28]

A female basketball player had a history of heat cramps for three years. She completed a three day twenty-four hour dietary intake log and whole body washdown (method of measuring electrolyte losses) resulting in sodium deficiency. The athlete then consumed more sodium following counseling sessions with a dietitian, and her muscle cramps were resolved. This case study likely demonstrated a sodium imbalance that occurred in an athlete who exercised in a mild environment (indoor gymnasium).[1] And highlights a need to educate athletes about two different issues related to maintaining electrolyte balance. Specifically, to not over-drink fluids before, during or after exercise, and also to consume an adequate amount of sodium in their diet to replace sweat sodium losses.[6]

Eichner et al., states the importance of a high sodium diet during times when intense activity occurs in hot environments. This could prevent athletes from having exercise associated muscle cramps, exercise associated hyponatremia or other adverse effects of sodium depletion.[7] Exercise associated hyponatremia (EAH) is the clinical illness that occurs when an individual has low levels of plasma sodium concentration.[4] The single most important precipitation factor to EAH is the over consumption of fluids, however, large sweat sodium losses and excess fluid retention are believed to be factors as well.[2, 10]

Environmental influences, individual body size (muscle mass, body surface area), age, sex, exercise (type, intensity, duration, frequency), as well as clothing and equipment worn and dietary intake of sodium all effect individual sweat rate and electrolyte losses. The intensity of exercise and duration of training endurance athletes participate in could cause large sweat rates and sodium losses, which could lead to decreases in athletic performance.[5,6]

There is strong evidence to state that fluid and sodium recommendations cannot be generalized.[3,7,10,11] Safety concerns arise when widespread guidelines are set for all people.[10] Individualized fluid and sodium consumption based on losses have practical implications for optimal performance and overall health of athletes.[9,11] Athletes who participate in activities that result in large sweat and sodium losses may need to supplement sodium beyond normal dietary intake. This leads the primary investigator to believe that endurance athletes who train for greater than two hours and are heavy salty sweaters need to increase daily dietary sodium intake to balance their sweat sodium losses.

Therefore, the problem statement is: Do endurance athletes, explicitly runners, replace adequate amounts of salt (NaCl) in their daily diet compared to their individual salt losses for a daily training session? The primary purpose of this study was to observe and calculate the dietary sodium and chloride intake compared to measured sweat sodium and chloride losses of distance runners over three consecutive days of training. The secondary purposes are; to determine dietary sodium (and NaCl) intake consistency across collection days, and to investigate the consistency of body weight, sweat rate and gross sweat loss over three consecutive days.

Based on the intended study, our hypotheses are as follows:

H_{01} There will be no differences in daily dietary sodium intake compared to sweat sodium loss during a single training session in endurance runners.

H_{02} There will be no differences in dietary sodium intake compared to sweat sodium losses in endurance runners over three days of training.

H_{03} There will be no differences in daily dietary sodium chloride (NaCl) intake compared to sweat sodium chloride (NaCl) loss during a single training session in endurance runners.

H_{04} There will be no differences in dietary sodium chloride (NaCl) intake compared to sweat sodium chloride (NaCl) losses in endurance runners over three days of training.

H_{05} There will be no differences in mean sweat rate in liters per hour over three consecutive days of training.

H_{06} There will be no differences in gross sweat loss in liters over three consecutive days of training.

H_{07} There will be no differences in body mass (kg) over three consecutive days of training.

Methodology

Participants

Recruitment was completed via email to specific athletes and/or coaches determined by previous good standing relationships with investigator(s) and the HEAT Institute. There were 10 competitive endurance athletes selected. Inclusion criteria stated; currently training athletes, at least 18 years of age, good standing health determined by a physician, and the completion of training sessions greater than 2 hours in length. Exclusion criteria consists of those who are less than 18 years of age, orthopedic or general medicine condition, underlying chronic condition affecting electrolyte imbalances, known thermoregulation disorder, abnormal blood pressure, supplementation of sodium, or hormone imbalances. All subjects voluntarily agreed to participate in the study and provided written informed consent. The Institutional Review Board for Human Subjects at West Chester University approved this study.

Procedures

The study was completed over three consecutive days per volunteer participant. Primary investigator collected baseline data; age, gender, height, weight. Participants were advised not to alter normal dietary intake on data collection days. Participants each completed three consecutive days of data collection. These training sessions extended greater than two hours in length. The dependent variables included; sweat sodium concentration, sweat rate, sweat loss, sweat sodium chloride loss, dietary sodium and sodium chloride intake, and body mass.

Day 1: Data Collection

On day 1 of data collection participants were advised to wear tight compression clothing for body weight measurements. They reported to the HEAT institute prior to activity and voided their bladder completely. The primary investigator recorded the participants' pre-exercise body weight using a DETECO physician's scale. Liquids anticipated to be consumed were also weighed on an electronic scale (g) and this weight was converted to mL and recorded. The primary investigator then placed sweat patches on the skin at two sites (forearm and low back).

Sweat Testing

The sweat testing process was completed each training session on all 3 days of data collection. Prior to training, participants voided their bladder completely and provided a body mass measurement which was recorded. There were two patches placed on each participant. Prior to the application of each sweat patch the sites were cleaned with an alcohol prep pad, dried with sterile gauze, cleaned with deionized water and dried a final time with sterile gauze. One patch was placed on the right low back 4 - 5cm from L4/L5 vertebrae, and the other on the right forearm over the belly of the brachioradialis muscle. Each patch was made of sterile gauze approximately 2.5 x 2.5-cm which was placed in the center of a 5 x 6cm transparent semi-permeable adhesive dressing. The combination of both forearm (.335) and low back (.665) sweat sampling was utilized to estimate total body sweat concentration.

The primary investigator removed each patch with tweezers after approximately one hour into exercise, making sure that the gauze was not over saturated. Each sweat patch was placed in an individualized and labeled sterile, low retention microcentrifuge tube. In the HEAT Institute, the individually labeled sweat samples were centrifuged for 4 min at 3,000 rpm (Eppendorf, Mini Spin Plus). This centrifuge process separates the neat sweat sample from the gauze in order for the sample to be analyzed. Each individually labeled sweat sample was diluted 2:1 with 50µl of the sweat sample and 100µl of diluent. The samples were mixed by hand and analyzed by an ion selective electrode analyzer (Roche, 9180 electrolyte analyzer) to determine the amount ($mmol/L^{-1}$) of electrolytes (Na^+, K^+ and Cl^-) in each sweat sample.

Sweat Rate

Sweat rate was determined for each individual participant. Each participant was weighed prior to training session while dressed in only his or her compression garments. The participants were advised to drink to thirst during the training bout and were supplied with pre weighed bottles of fluid prior to their training session. The participants were instructed not to spit any of the pre-weighed water out or utilize restroom facilities until after the post exercise weigh out was completed. After the participants' completed their training session, post-exercise body weight was recorded and the remaining fluids were weighed which allowed the total volume of fluid consumed to be calculated. Sweat loss and sweat rate was then calculated using the following formula. Pre exercise weight (kg) - Post exercise weight (kg) + fluid consumed (kg) divided by length of exercise (hours) = sweat rate kg/hr. To complete this calculation, weight in pounds was converted to kg by dividing weight by 2.2. In addition, fluids consumed in grams were converted to kilograms by dividing by 1000.

Dietary Analysis

The evening before the first day of collection, the participants were contacted via email to remind them of the dietary analysis portion of the study. This was to ensure they understood they must send pictures via cellular device of all foods and beverages they consumed to the primary investigator throughout each day for the three days of data collection. Reminder messages were sent throughout the day at meal times (7am, 12pm, 6pm) and again prior to bed 10pm. A description of consumed food accompanied each photograph that was sent to primary investigator. If a meal was not completed in entirety another picture was sent to determine portion size consumed. The primary investigator utilized a serving size chart from the Dairy Council of California Healthy Eating. This guide utilized one's hand to draw conclusions of proportions. A dietary analysis was completed using Food Processor Nutrition Analysis Software ESHA. All consumption was inputted into the software by the primary investigator and labeled by individual and day. The ESHA software provided daily sodium intake. Sodium Chloride (salt) was estimated with calculations using the daily sodium reported from the ESHA software.

Data Collection Days 2 and 3

The exact same protocol was completed on the second and third days of data collection as described in detail for day one. Briefly, the participants continued to send primary investigators photographs and descriptions of all food and beverage consumptions. Prior to practice they reported to the HEAT Institute to be weighed, have sweat patches applied, and fluids for training weighed. Following the completion of training for that day, the participants reported back to the HEAT Institute to be weighed again, have sweat patches removed which were placed in individually labeled tubes to be analyzed, and fluids weighed again to calculate the volume consumed during training.

Sodium and Sodium Chloride Calculations Via Sweat Loss

Total body sweat sodium was calculated using the weighted means for the forearm (0.335) and low back (0.665). This sodium concentration ($mmol/L^{-1}$) was converted to mg/L by multiplying by the atomic weight (23) and dividing by the valance (1). The total amount of sodium lost per day was calculated by multiplying the concentration of sodium (mg/L) by the volume of sweat (L) lost for that day. Similarly, the chloride concentration ($mmol/L^{-1}$) was converted to mg/L by multiplying by the atomic weight (35.4) and dividing by the valance (1). The total amount of chloride lost per day was calculated by multiplying the concentration of sodium (mg/L) by the volume of sweat (L) lost for that day. Finally, daily sodium chloride losses were determined by the sum of both sodium and chloride lost per day.

Statistical Analysis

A 2 x 3 ANOVA with repeated measures on time (days 1, 2 and 3) were run for both sodium and NaCl. This determined if interactions existed between intake and loss. One-way ANOVA's were used to determine if differences existed in body weight, sweat rate or sweat losses over days. Basic linear correlations were run comparing all three days of intake to all three days of loss for both sodium and NaCl. Independent t-tests were used to determine if differences existed for both sodium and NaCl intake versus loss on each individual day. Values are presented as means and standard deviations, and statistical significance was chosen at $p<0.05$.

Results

Environment

Daily temperatures remained consistent across days of data collection (table 1).

Table 1: Temperature Mean

Day 1 (°F)	Day 2 (°F)	Day 3 (°F)
44.3 ± 2.4	43.5 ± 3.7	39.8 ± 4.9

Participants

Ten participants volunteered for the study and were students at West Chester University who were currently training for running endurance events. All 10 volunteers were apprised of the risks and benefits of participation, signed consent forms and completed all parts of the study. The participants' characteristics are displayed in table 2.

Table 2: Participant Characteristics (n=10)

Age (yr)	Height (cm)	Body Weight (kg)
20.5 ± 1.5	173.2 ± 12.7	65.5 ± 10.6

There were no significant differences in body mass (kg), which remained extremely consistent across days as shown in table 3.

Table 3: Participant Body Mass

Day 1 (kg)	Day 2 (kg)	Day 3 (kg)
65.6 ± 10.5	65.5 ± 10.5	65.7 ± 10.5

Dietary Sodium Intake and Sodium Sweat Loss

A two-way ANOVA showed that a significant difference existed between sodium intake and loss over three days ($F_{1,19} = 20.89$, p = .00024). Sodium intake on Day 1 (4,013 ± 2,005) was different from sodium loss on Day 1 (1,571 ± 1,058) as determined by independent t-test (t = 3.41, p=.0031). Similarly, independent t-test showed that sodium intake on Day 2 (3,152 ±

1,597) was different from sodium loss on Day 2 (1,089 ± 1,407), t = 3.07, p=.0066), and sodium intake on Day 3 (3,983 ± 2,072) was different from sodium loss on Day 3 (882 ± 739), t= 4.46, p=.0003). The ANOVA showed no significant difference in sodium (Na+) intake or sodium loss across the 3 days.

The linear correlation did not show a significant relationship between sodium intake and sweat sodium loss. All data for sodium intake and sodium loss per day is in table 4.

Table 4: Mean Sodium Loss vs. Mean Sodium Intake

Sodium (mg)	Day 1	Day 2	Day 3
Sodium Intake	4,013 ± 2,005 *	3,152 ± 1,597 *	3,983 ± 2,072 *
Sodium Loss	1,571 ± 1,058	1,089 ± 1,407	882 ± 739
Sodium Intake Range	1,406 – 6,760	1,253 – 6,638	1,073 – 5,334
Sodium Loss Range	342 – 3,637	313 – 5,023	179 – 2,733

* Significantly different from sodium loss, p <0.01

Dietary Sodium Chloride Intake and Sodium Chloride Sweat Loss

In terms of practical application, table salt (NaCl) was estimated in mg based on sodium intake from the ESHA software. Chloride was estimated from sodium intake and the sum of both determined NaCl intake. Similar to sodium measures a two-way ANOVA showed significant difference between NaCl intake and loss over three days ($F_{1,19}$ = 16.96, p = .000645). On Day 1, NaCl intake (10,190 ± 5,091) was different from NaCl loss (3,747 ± 2,446), t=3.61, p=.0020). NaCl intake on Day 2 (8,004 ± 4,055) was different from loss (2,694 ± 3,445), t =3.16, p=.0054, and on Day 3 NaCl intake (8,584 ± 5,289) was different from (2,150 ± 1,860), t =3.63, p=.0019. The ANOVA showed no significant difference in NaCl intake or loss across days.

Data for sodium chloride intake and sodium chloride loss per day is in table 5.

Table 5: Mean NaCl Loss vs. Mean NaCl Intake

Sodium (mg)	Day 1	Day 2	Day 3
NaCl Intake	10,190 ± 5,091 *	8,004 ± 4,055 *	8,584 ± 5,289 *
NaCl Loss	3,747 ± 2,446	2,694 ± 3,445	2,150 ± 1,860
NaCl Intake Range	3,569 – 17,165	3,182– 16,855	1,606– 17,183
NaCl Loss Range	807– 6,409	736– 12,347	867– 3,076

* Significantly different from NaCl loss, p <0.01

Sweat Rate

Calculated sweat rates displayed variability that ranged from 0.19 – 1.40 $L \cdot hr^{-1}$. The one-way ANOVA showed no significant differences in sweat rate between the training sessions on the three days ($F_{2,27} = 1.61$, $p > 0.05$). Similarly, there were also no differences in gross sweat loss each day of the three consecutive training sessions ($F_{2,27} = 1.27$, $p > 0.05$). Table 6 displays the descriptive data for sweat rate and gross sweat loss.

Table 6: Sweat Rate and Gross Sweat Loss

	Day 1	Day 2	Day 3
Sweat Rate (L/hr)	0.76 ± 0.38	0.56 ± 0.25	0.53 ± 0.31
Sweat Loss (L)	1.00 ± 0.54	0.75 ± 0.43	0.69 ± 0.40

Discussion

Sweat Rate

This study was completed during late February and early March when the weather was comfortable if not colder, and sweat rates were not as high as would be expected during warm and humid summer months. A well-known factor in sweat and therefore sodium loss is the environmental conditions in which an athlete exercises. This study calculated sweat rates that displayed large variability ranging from 0.19 – 1.40 $L \cdot hr^{-1}$. A majority of research studies that focus on fluid and electrolyte balance take place in the heat and humidity of summer, usually during times such as pre-season training.[3,5,7,13,17,19,25] Specifically, preseason soccer sweat rate range from 1.2 - 1.67 L/h, cross country sweat rates range 1.04 – 2.49 L/h, and football sweat rates range from 1.1 – 3.6 L/h.[5,19] Fowkes Godek et al., reported that when comparing male cross country runners and football players sweat rates during preseason cross country athletes averaged 1.77 L/h and football players averaged 2.14 L/h.[5] Football players had greater daily losses and higher fluid volumes consumed.[5] Lower sweat rates for this study compared to previous research could be a result of the climate's effect on sweat rate. Fowkes Godek et al., reported a mean temperature of 83.1°F during football and cross country preseason practices and Maughan et al., reported a mean temperature of 79.7°F during soccer practice.[5,19] Unlike the previous studies this study reported a mean temperature of 42°F during data collection.

It would also appear that participants need better tools and more education about the individualized replacement needs as periodization of training throughout the year changes. The important intrinsic (not related to environmental conditions) factors that influence sweat rate are physical conditioning, acclimatization, hydration status, exercise intensity, physical size, and the amount of clothing and/or equipment worn.[5] In terms of the specific participants of this study (distance runners) compared to data from soccer players or football athletes, it would not be anticipated that they have a very high sweat rate as they were not heat acclimatized and the intensity of their workouts was likely not that high as they were well conditioned (end of the season), and were in preparation for championship meets and therefore tapering. At this point in their training regimen they are not increasing duration or intensity, and they are maintaining their fitness status without performing extremely intense workouts. Importantly, compared to the football population, their physical size is small (mean mass 65.51kg) and distance runners wear form fitting clothing with no extra equipment.[3,5,6,7]

Dietary Sodium Intake and Sweat Sodium Loss

Results from this study clearly indicate that the participants consumed greater amounts of sodium on a daily basis compared to sodium sweat losses. Greater overall dietary sodium intake was not an anticipated finding, particularly with respect to the fact that only one participant out of the 10 subjects lost more sodium via sweating than the consumed in their diet for one day. This research study had results supporting mean sodium intake of 3.7 ± 1.9 g and mean sodium loss of 1.2 ± 1.1 g. Previous research showed that very high sweat rates and sweat sodium losses for athletes, such as NFL players during preseason two-a-days, resulted in insufficient sodium replacement and need for supplementation. For example, Fowkes et al., reported sodium losses in NFL backs, mid-sized players such as linebackers and quarterbacks, and then linemen of 7.6 ± 3.9, 9.9 ± 5.3 and 12.5 ± 7.8 g/d, respectively.[7] And remarkably, sweat sodium losses per day ranged from 2.3 to over 30g in individual players.[7] Additionally, Bergeron studied tennis players and found sweat sodium loss ranged from 1.37 to 4.77 g/h,[2] and Holmes et al., determined individual sweat sodium loss for cycling and triathlon participants had losses as great as 4.5g.[18]

Although sweat rate varies from one individual to another, variations in sweat sodium (and chloride) concentration are even more considerable. The variability between sports and also the large ranges within a sport suggest individual variations of sweat concentration, 20–62 mmol/L^{-1} in soccer, 54–73 mmol/L^{-1} in ice hockey, 17–73 mmol/L^{-1} in marathon running.[14] In a study by Fowkes Godek et al., American football players ranged from 15 mmol/L^{-1} to 99 mmol/L^{-1} .[7] It is the tremendous differences in sweat electrolyte concentration that accounts for the huge differences in sweat sodium losses, and the primary reason why athletes cannot be treated the same with respect to dietary sodium (and NaCl) needs. The mean sweat sodium concentration in our 10 subjects was 61.17 mmol/L^{-1}, and ranged from 20.35 to 117.22 mmol/L^{-1} The mean sweat sodium in American football (55.9 ± 36.8 mmol/h) and endurance athletes (51.7 ± 27.8 mmol/h) was similar, with soccer (34.6 ± 19.2 mmol/h), basketball (34.5 ± 21.2 mmol/h), and baseball (27.2 ± 14.7 mmol/h).[7,14,19,22] The differences in mean sweat electrolyte concentration, aside from the tremendous individual differences that exist, challenge the idea for "normal" values or guidelines for replacement for the average individual. In terms of RDA for sodium, daily recommended values may not be suitable for every athlete. However, the RDA for our runners would be sufficient.

There are several explanations for the results of this study. The primary finding that the participants consumed sodium in excess of what they lost via sweating could be an outcome of education and awareness of electrolyte replenishing. These athletes may be aware that proper fluid balance and the maintenance of stable body weight is dependent on sodium intake. The Athletic Training and Sports Medicine staff at West Chester University promotes education about the proper and accurate information of fluid and electrolyte maintenance including salting foods during pre-season. It can be known that athletes need more knowledge in regards to how much replenishing of sodium is necessary and when if needed they should increase sodium chloride intake into their body.

Participants reported little variety in their diets, and admitted to giving little to no thought to adjusting their diet in anticipation of expected training intensity. Given these observations, it can be assumed that participants do not routinely vary dietary consumption to accommodate for training periodization. For example, if sweat sodium losses are lower than preseason reports, sodium intake should be decreased. Athletes should be educated about appropriate sodium intake compared to sweat loss as environmental factors such as temperature and humidity change. Some football players during preseason are heavy salty sweaters and need to supplement sodium however, that may not be the case during spring football when the temperature is lower and humidity is much less. Athletic trainers should be educating athletes about how to fuel their body with appropriate amount of meals and calories per day and also best performance options such as when and how much sodium is necessary. If significant losses of fluid occur one can assume they may need to add more sodium into their dietary consumption. Specific attention to functional eating or eating based on anticipated training and individualized external factors should be practiced by athletes.

The most practical way to estimate large sweat sodium losses is to measure sweat rate. Simple, inexpensive, and very quick one must be weighed prior to practice, post practice and weight adjusted for fluid intake. This will provide an individual will an estimate of how much fluid they are losing each training session. Along with education of sodium replacement, athletic trainers should continue to encourage athletes to “drink to thirst” to avoid adverse health conditions from overdrinking or trying to replace all fluids lost.

In terms of dietary sodium intake, it should be noted that a majority of food consumed by participants of this study was from the university dinning hall. When food is prepared for large numbers of people it is generally created to maintain freshness and does so with large amounts of sodium chloride. This type of food may have been an unintentional source of increased participant sodium intake.

Although time consuming, athletes can monitor their sodium intake using food apps or writing down totals from food labels in order to regulate how much sodium they are consuming. Awareness of sodium intake should aide in appropriate amounts of sodium consumption based on training intensity and environmental factors. Athletic trainers and other health care professionals can use this information from a total team approach or even individual approach to educate athletes for best performance for their needs.

Limitations

Limitations to this study include the oversight for the need to collect the urine in the bladder post exercise for volumetric measurements. This may have caused a slight over-estimation of sweat rate, although the athletes were instructed to drink according to thirst, which should have minimized fluid intake and therefore the production of urine during the training bouts. This study was limited to 10 total participants for data collection. A larger sample size would have assisted in more accurate results. The dietary analysis is also dependent on a subjective estimate of portion size of what participants consumed by the primary investigator. Additionally, a final limitation includes the inability to specifically control the intensity of the training sessions, so that they were equal over three consecutive days of training.

Future Research

It appears that more research is needed in terms of understanding fluid and electrolyte balance among endurance athletes at the collegiate level. Future research should include surveys of runner's knowledge about the need for testing to address their individual fluid and electrolyte needs. It would be helpful to know if educational interventions would assist these athletes in understanding their dietary intake of sodium. Understanding the effects that acclimatization and training in the hot summer months have on sweat rate and electrolyte concentrations in this cohort of athletes would also be of interest. Future research in specific age groups and gender and their ability to maintain fluid and electrolyte balances when exercising; during adolescence, college, post college, over 50 years old, over 75 years old. Additionally determining the effects of replacing sodium losses during activity compared to post exercise. Investigation into the role of sodium levels leading up to a demanding event, at the start of the event, during and post. Researchers should investigate individual sweat rates and sweat sodium levels for an entire training period (out of season, pre-season, in-season, and post season) monitoring changes.

Conclusion

The participants in this study exceeded individual physiological needs for sodium compared to individual sweat sodium losses. Compared to their current training intensity and environmental factors supplementation is not recommended. It is important not to consume more sodium than necessary, as there are risks that could affect health and daily life. Over consumption of sodium could increase risk of hypertension or renal disease. The previous literature and this study support the notion that sodium consumption is individualized per person compared to their specific sweat sodium losses.

The purpose of this study was to compare dietary sodium intake and losses via sweat sampling in endurance athletes during daily training sessions. The significance of this study lies in the determination that supplementation of sodium in endurance athletes is variable for each individual based on their sweat sodium losses. Following the results of this study athletic trainers and other health care professionals should educate endurance athletes about dietary intake and when they may or may not require increased sodium intake or even supplementation.

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Appendices

Appendix A: IRB Approval

WEST CHESTER UNIVERSITY

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

Protocol ID # 20191217AR1

TO: Christina Gotthold, Sandra Fowkes Godek
FROM: Nicole M. Cattano, Ph.D.
Co-Chair, WCU Institutional Review Board (IRB)
DATE: 3/25/2020

Project Title: A Comparison of Dietary Sodium Intake and Sweat Losses during Endurance Training Sessions
Date of Approval for Revision: 3/25/2020**
Please note that the original end date of your approved protocol still applies

☒**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:

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

Appendix B: Recruitment

Want to learn more about your body?

Want to gather information that could help with optimal performance?

*****Participate in this research study!*****

Purpose: Determine if the amount of salt you sweat during exercise is equal to the amount of salt you ingest.

How: Wear a sweat patch (the size of a band-aid) on your forearm and low back during exercise for 3 consecutive training days AND log all food and drink ingested during these three days.

Results: Are the results equal? Do you sweat more salt than you eat? Vis-versa? After completion of this research study and data analysis you will have this individualized information!

Recruitment Email:

Greetings,

On behalf of West Chester University Sports Medicine Department Christina Gotthold is inviting you to participate in her research study. I am a graduate student at West Chester University working alongside Dr. Sandra Fowkes Godek. Our research study will be investigating sodium turnover and sweat electrolyte difference for endurance athletes. We are emailing you to ask if you would like to volunteer for our studies. Your participation is completely voluntary and all of your results will be kept confidential.

- **Study:** Sodium turnover- Record three-day food log, and wear sweat patch application on forearm and low back during exercise for 3 days. You will be able to determine sodium supplementation outside one's diet intake to ensure you maintain fluid balance during exercise.

If you are interested, please see the attached documents for the informed consent. Please, read and sign both of the informed consent documents and email a copy of the signed documents to cg913696@wcupa.edu.

If you have any questions, please do not hesitate to contact us.

Thank you for your time.

Christina Gotthold
cg913696@wcupa.edu
856-873-6303
West Chester University

Appendix C: Informed Consent

Informed Consent

Project Title: Dietary Sodium Intake and Sweat Losses during Training Sessions for Collegiate Runners.

Investigator(s): Christina Gotthold; Sandra Fowkes Godek

Project Summary:

Participation in thesis research project is voluntary. The investigation will be completed by Christina Gotthold as part of her Master's thesis to determine the need for sodium supplementation for collegiate runners following training sessions. This will require volunteer participants to log dietary intake for three days and monitor sodium losses from sweat each day during single training sessions. The study procedures are explained below. There is minimal risk of possible discomfort associated with this data collection and valuable information about individual sweat rate and sweat electrolyte concentration. This information will assist in understanding of fluid and electrolyte needs on training days.

If you would like to participate West Chester University requires you agree and sign a consent form. You may ask Christina any questions to help you understand this study. If you don't wish to be a part of this study, it will not 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 at any time.

1. **What is the purpose of this study?**
    - Investigate sodium losses in comparison to dietary intake in order to determine supplementation of sodium when training.
2. **If you decide to be a part of this study, you will be asked to do the following:**
    - I understand this study will take three consecutive days of participation.
    - As a subject in this study, I agree to document dietary intake over three days of training. Throughout the three days of testing, I will not alter my diet outside of my norm. I will document all dietary intake including liquid intake and food intake in addition to amounts and proportions eaten.
    - Prior to day one exercise session, my body weight is measured while wearing compression shorts and a fitted top.
    - I understand a researcher will apply a sweat patch on forearm and low back after areas are cleaned.
    - I understand I will report back post exercise for sweat patches to be removed and carefully placed in identified tubes.
    - I understand for a total fo three days sweat samples and dietary intake will be documented.
    - Participants sign consent to permit researchers to perform sweat and dietary analysis. If questions, contact Christina Gotthold, LAT, ATC at (856)-873-6303 or Dr. Sandra Fowkes Godek, PhD, ATC at (610) 436-2342.
3. **Are there any experimental medical treatments?**

- No

4. **Is there any risk to me?**
   - I understand the minimal risk associated with exercise activity. If participation in exercise causes me to become ill, dizzy, disoriented, experience nausea, etc. I will terminate exercise.
   - I understand there is minimal discomfort with awareness of sweat patch while participating in activity.
   - If I become upset and wish to speak with someone, I may speak with Dr. Sandra Fowkes Godek, PhD, ATC, and Christina Gotthold, ATC.
5. **Is there any benefit to me?**
   - I understand that the research study will provide me individualized information pertaining to dietary intake and sodium losses while training. I understand I will be provided individual sweat concentration post exercise. This information will assist me in understanding fluid needs and electrolyte needs when participating in exercise or post exercise.
6. **How will you protect my privacy?**
   - I understand my records will be kept confidential. Only Christina Gotthold and Sandra Fowkes-Godek and the Institutional Review Board will have access to my name and results.
   - My name will **not** be used in any reports.
   - I understand all records will be stored in a locked cabinet in Sturzebecker Health Sciences Center, Room HEAT Institute, which will also be kept locked.
   - All documents and information related to this study will be kept confidential in accordance with all applicable federal, state, and local laws and regulations. Medical records and data generated by the study may be reviewed by the West Chester University's Human Subjects Review Board.
   - Results of this study may be published. If any data is published, individuals will remain anonymous and not be identified. The only persons with access to the data will be Christina Gotthold 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:** Christina Gotthold, CG913696@wcupa.edu
     - **Secondary Investigator:** Sandra Fowkes Godek at 610-436-2342 or SFowkes-Godek@wcupa.edu For any questions about your rights in this research study, contact Dr. Gautam Pillay through the ORSP at 610-436-3557.
9. **What will you do with my Identifiable Information/Biospecimens?**
   - Once the sweat sample has been collected 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:________________

Appendix D: Two way ANOVA and One-Way ANOVA Tables

Two-Factor ANOVA with Repeated Measures of One Factor

Sodium (Na+) ANOVA Summary

Source	SS	df	MS	F	P
Treatment [between groups]	179521828.64	19			
A	96420723.96	1	96420723.96	20.89	0.000237
Subjects within A	83101104.68	18	4616728.04		
Within Subjects	54747701.27	40			
B	4515535.11	2	2257767.55	1.71	0.195230
A x B	2757643.2	2	1378821.6	1.05	0.360409
B x Subjects within A	47474522.96	36	1318736.75		
Total	234269529.91	59			

Sodium Chloride (NaCl) ANOVA Summary

Source	SS	df	MS	F	P
Treatment [between groups]	1136194013.71	19			
A	551238149.75	1	551238149.75	16.96	0.000645
Subjects within A	584955863.96	18	32497548		
Within Subjects	278726512.61	40			
B	34591999.78	2	17295999.89	2.6	0.088165
A x B	4243208.4	2	2121604.2	0.32	0.728193
B x Subjects within A	239891304.43	36	6663647.35		
Total	1414920526.32	59			

One-Way Analysis of Variance for Independent Samples

Sweat Rate ANOVA Summary

Source	SS	df	MS	F	P
Treatment [between groups]	0.327787	2	0.163893	1.61	0.218492
Error	2.75176	27	0.101917		
Total	3.079547	29			

Gross Sweat ANOVA Summary

Source	SS	df	MS	F	P
Treatment [between groups]	0.546887	2	0.273443	1.27	0.297077
Error	5.82245	27	0.215646		
Total	6.369337	29			