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Influence of Hydration Status on Running Performance and Makers of Psychological and Physiological Stress in High School Cross Country Runners

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INFLUENCE OF HYDRATION STATUS ON RUNNING PERFORMANCE AND MARKERS OF PSYCHOLOGICAL AND PHYSIOLOGICAL STRESS IN HIGH SCHOOL CROSS COUNTRY RUNNERS

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Abstract

Adequate hydration is an important attribute to an individual's health and wellbeing. This is highlighted in athletic populations, who are at great risk for hypohydration, regardless of age, sex, and sport. The rampant hypohydration observed in athletes is present at all levels of competition, from professional athletes, with access to substantial monetary and nutrition support to division 3 and recreational athletes who often face monetary challenges. This trend continues to trickle down to lower levels of competition, such as high school, where athletes often practice and compete in dehydrated states. Practicing in these hypohydrated states can cause health issues such as cardiovascular impairment and increases the risk of accidents or death in extreme environmental conditions. Furthermore, the magnitude of hypohydration is associated with poorer health outcomes and can lead to cognitive impairments. Some of these associated outcomes are confusion, coma, kidney failure, muscle weakness, short-term memory, procedural memory, longer-term memory, and even higher thinking tasks. There are many factors involved that can cause individuals to become hypohydrated such as inadequate fluid intake, diet, activity, sweat rate, core temperature, and environmental factors such as weather, heat, and humidity. Interestingly, low fluid intake is the leading factor responsible for dehydration, the process of reducing total body water content, especially in individuals who work in hot environments, military personal, and athletes. Although the impact of hypohydration on professional athletes and occupational workers have been well characterized, there is a dearth of information on the effect of hypohydration on younger populations, such as high school athletes specifically cross-country runners in south Louisiana. In this context, the proposed study will attempt to characterize the effects acute bouts of exercise on the hydration status of high school cross-country runners. Furthermore, we will assess the impact of increased hydration on cognitive and running performance in high school cross-country runners.

Chapter 1. Introduction

1.1. General Introduction

Adequate hydration is an important attribute to an individual's health and wellbeing[1, 2]. Specifically, maintaining a normal body water-content, termed euhydration[3], is of paramount importance for any population, especially athletes regardless of age, sex, and sport. Indeed, highly active individuals are at an increased risk for being hypohydrated [3, 4], a severe deficit in body water content [5]. The rampant hypohydration observed in athletes is well characterized at high levels of competition such as division 1 sports where there is a lot of control and support for these athletes, with around 66% of Division 1 athletes being hypohydrated independent of whether they are seniors or freshman [3]. While the high prevalence of hypohydration in high level athletes is concerning, it is important to note that lower division athletes appear to be at further risk for inadequate hydration status with up to 84% of division 3 male athletes who have been shown to be hypohydrated [6]. This pattern continues even at lower level competitions were high school athletes are practicing and competing in hypohydrated states [7-10], which impacts health [1, 2] and in heat-related incidences can even be fatal. As athletes become hypohydrated their performance typically suffers with athletes being slower in sprints and long-distance runs [11]. Distance runners who are hypohydrated have detriments to performance as well as pacing during competition [12, 13]. Hypohydration can further affect an athletes' ability to perform skilled techniques for a variety of sports adding to the list of performance issues for hypohydrated athletes [11, 13]. While hypohydration has performance detriments there are even larger and in some cases life-threating health detriments. Indeed, hypohydration is often associated with nausea and headaches, but in the most severe cases, extreme hypohydration can be lethal. As hypohydration progresses to dangerous levels confusion, coma, kidney failure, and muscle weakness are seen. In addition to its detrimental impact on physiological systems, chronic hypohydration is also associated with negative effects on cognition with short-term memory, procedural memory, longer-term memory, and even higher thinking tasks [11, 14]. These cognitive issues are an obvious hinderance to individuals in a school setting [14] independent of age or gender, but can also affect those in the work place where cognitive function and decision making can influence work performance [15]. The workplace issues with hypohydration do not end with just cognitive detriments but there is also safety, productivity, and morale aspects that are negatively affected by hypohydration [15]. Many factors are involved that can cause individuals to become hypohydrated such as inadequate fluid intake, diet, activity, sweat rate, core temperature, and environmental factors such as weather, heat, and humidity. The environmental factor such as weather can change ambient heat and humidity with a quick sudden storm or a day that is sunny with no clouds or wind around. As these environmental factors affect the way the body sweats and how the body tries to lower its core temperature. Sweat rate, activity, and heat/humidity work hand in hand as someone who is active in these

hot humid environments their sweat rate increases while their ability to lower their core temperature through sweating decreases [5, 16]. In a hot climate the effects of hypohydration on core temperature can be exaggerated leading to health issues rapidly [5, 17]. As sweat rate increases dehydration becomes more likely, which adds to increasing an individual's core temperature. Controlling core temperature when hypohydrated while in a hot and humid environment such as Louisiana, can be problematic leading to some of the health issues mentioned previously. In this regard, the correct diet and fluid intake can help offset the aforementioned environmental and physiological factors of hypohydration. Diet and fluid intake directly affect hydration level with fluid intake having the largest impact of the two. Indeed, fluid intake is one of the most important ways to maintain an euhydration, normal body water, content and avoid becoming hypohydrated. In parallel, inadequate fluid intake is one of the biggest issues leading to voluntary hypohydration, an increasing occurrence in those who work in hot environments, military personal, and athletes [8, 15, 16].

Collectively, these factors create a "hydration issue" that can be observed in many populations in America ranging from young children to the elderly [15, 18, 19]. Exemplary of this "hydration issue" it has been observed that nearly 55% of children ages 6-19 were hypohydrated [19]. Adding to this alarming "hydration issue", studies have shown that not only are children hypohydrated, but that they are starting the school day in these hypohydrated states [20, 21]. Nearly 85% of children were hypohydrated the morning of school days and this number only dropped to 75% at the end of the school day, suggesting a strong need to have hydration plans in schools [21]. The rampant hypohydration in schools continues with high school football athletes with on average 70% of these athletes being consistently hypohydrated [22]. This "hydration issue" is also evident in adult populations ranging from 20-74 years of age with almost a third of this adult population being hypohydrated [23]. Hypohydration is a very common issue for the elderly being a significant cause of morbidity, mortality, and health care costs in elderly populations with elderly who are hospitalized for hypohydration having a high probability of dying within a year [18]. Even though we have large amount of information about hypohydration in many populations there are still some population that have not been looked at such as high school athletes specifically cross-country runners. There is a need to look at this population and see if they are at risk for being hypohydrated and if so, how can we get this population back to euhydrated status.

1.2. Specific aims

SA1: Determine whether high school cross country runners may be at risk for hypohydration during in-season training.

Hypothesis: We hypothesis that this population is at risk for hypohydration during in-season training.

To test this hypothesis, we tested these athlete's hydration status under their normal training conditions before and after a 5K time trial. Furthermore, we correlated their running time with pre- and post-exercise hydration status.

SA2: Characterize the impact of increasing hydration level on performance and exercise-induced hypohydration.

Hypothesis: We hypothesis that increasing hydration levels are associated with improvements in performance (5K time trial) and cognitive function in high school cross-country runners.

To test this hypothesis, we implemented a simple hydration strategy and test hydration status before and after a 5K time trail and compare these to baseline measures.

The primary objective of this project was to determine if high school cross country runners are at risk for hypohydration. We hypothesize that this population is at risk for being hypohydrated and would benefit from a hydration strategy. The secondary objective of this project was to determine if there are effects of euhydration on performance and exercise-induced hypohydration. We hypothesize that being euhydrated will lead to better performance on a 5K time trial versus being dehydrated.

1.3. Hydration on overall Health

Water may play a protective role in overall health including kidney disease, and higher total fluid intake has been seen to lower the risk of kidney stones and cardiometabolic health issues [2]. High fluid intakes are also associated with reduced risk of urinary tract infection, mitral valve prolapse, and coronary heart disease [1], including weak supporting evidence that fluid intake may reduce the risk for colon and urinary tract caner [1]. Additionally, increased hydration is associated with mental health benefits including better higher thinking, short-term memory, and procedural tasks than individuals who are hypohydrated [14, 24]. The human physiology also benefits from being adequately hydrated with lower core body temperatures, mean blood pressure, and heart rates when exercising [4]. Physiological benefits seen with adequate hydration is increasingly important in hot environments [5]. The decreases seen in core body temperatures and heart rates are indispensable to athletes performing in these hot environments were core body temperature and heart rate are directly correlated with performance outcomes [5]. For any individual a hydration plan is of paramount importance to maintain a euhydrated status and avoid the negative health connotations of being hypohydrated.

1.4. Effects of Hypohydration on overall health

Hypohydration can negatively affect anyone's overall health and can even have severe consequences with extreme cases of an 8% fluid deficit or more causing death [1]. Hypohydration is associated with confusion, coma, kidney failure, and muscular weakness [25].

Symptoms of hypohydration also include nausea and headaches, although these symptoms are associated with many other medical issues [25]. Illnesses connected to hypohydration include kidney stones, directly related to chronic hypohydration, while mild hypohydration may play a role in kidney stone, constipation, exercise asthma, urinary tract infections, hypertension, coronary heart disease, venous thromboembolism, and cerebral infarct [26, 27]. Chronic dehydration is also associated with impaired renal, gastrointestinal, immune function and delirium [28], with some evidence for hypohydrations role in bladder and colon cancer albeit not strong or consistent [26]. Apart from illnesses and symptoms hypohydrated is linked to impaired cognitive function[1] and this impaired function can cause adverse effects on an individual's tracking and coordination abilities [25]. More noticeable detriments of hypohydration is in the human body's ability to exercise. The physiological effects of hypohydration during exercise include decreased cardiac output, blood volume, core temperature, rate of percieved exertion, and decreased ability to recover [5, 12, 28]. Obviously, theses physiological changes that occur during exercise due to hypohydration cause decreased athletic performance with cardiac output and rate of percieved exertion having direct effects on an individual's ability to complete the same work as their euhydrated counterpart [5, 12]. In hot environments this decreased ability to perform the same work as a euhydrated individuals becomes even more apparent, as the hot environment exacerbates hypohydrations effect on core temperature and blood volume only further decreasing one's ability to perform [5, 12]. These hot environments also can exacerbate hypohydrations effect on cognitive function compared to euhydrated individuals [24].

1.5 Hydration on cognition

For individuals who are euhydrated there are a multitude of positive results. Children who are hydrated do significantly better on short-term memory tasks and slightly better on procedural memory tasks, perceptual tasks, long-term memory retrieval, and higher thinking, when compared to their age-matched hypohydrated counterparts [14]. Euhydrated children also have more vigor than those who are hypohydrated [21]. Much of the evidence provided attests to how hydration can be an important factor to students and student-athletes having academic success with higher thinking, short-term memory, and procedural memory task being effect by hydration status [14]. Interestingly however, children who are euhydrated perform better on short-term memory tasks, while they tend to perform worse on verbal analogy tasks compared to hypohydrated children suggesting that hydration may not improve scores in all cognitive tests [21]. Adults who are euhydrated also have benefits in short-term memory and have decision-making responses faster than those who are hypohydrated [24]. Studies have shown that simple rehydration following chronic hypohydration helps to alleviate the detriments to cognitive performance[24], but these detriments will be alleviated with time regardless of rehydrating [24]. Although there is evidence that cognitive performance will return to normal after being hypohydrated, populations at high hypohydration risk seem to

have improved cognitive performance with fluid consumption and bettered hydration status [29].

1.6. Hypohydration on Cognition

Even though normal cognition performance returns with time regardless of rehydration strategy [24], there is still concerns for cognitive performance when hypohydrated. Hypohydration is linked to impaired cognitive function [1], with mild hypohydration causing negative changes in mood and cognitive functions [28]. Even low to moderate hypohydration can have a negative impact on cognitive function and alertness, and that heat stress can play a large role in the impact that hypohydration has on this functions [28], with hypohydration having a negative impact on decisional and perceptual tasks [14]. Contradictory to the evidence provided, Fadda, Rapinett [21] found that hypohydration actually improved the performance on a verbal analogy test. Although in high risk hypohydration populations a correlation was observed between hydration status and cognitive performance and that for other populations there may not be a relationship between hydration status and cognitive performance [29]. Concerningly, hypohydrated children also performed inferiorly to euhydrated children on short-term memory, procedural memory, perceptual, long-term memory retrieval, and higher thinking tasks. Furthermore, hypohydration can also significantly increase the feeling of tiredness and impair concentration, alertness, tracking performance and coordination [25]. Across multiple sports hypohydration has been observed to impaired vigilance, working-memory reaction time, decision-making time, and reactive agility [11]. Although other cognitive tasks such as fine motor speed, visual perception, mental concentration, visuo-motor reaction time, and math unaffected by hypohydration [11], the negative effects of hypohydration do not stop at cognitive function especially in athletic populations.

1.7. Hydration on exercise physiology

An important function of hydration on the human body occurs during exercise where hydration status can have large effects on exercise physiology. Hydration protocols during spinning exercises prevented physical stress as evidenced by lower core body temperatures, mean blood pressure, and heart rates compared to when fluid was not available, and adequate hydration was not able to be maintained [4]. Individuals exercising and following hydration protocols would have better cardiovascular function than those who did not, due to having lower heart rates and mean blood pressure, while working at the same intensity as their hypohydrated counterparts [4]. Rectal temperature did not increase as high during 90 minutes of exercise for full fluid replacement compare to half fluid replacement and no fluid replacement [30], which suggests that in hot environments those who implement a full fluid replacement plan would perform better than those who did not [5, 12]. Runners with enhanced hydration status had many benefits during submaximal trails with lower core temperatures, decreased cardiovascular strain, decreased perceptions of exertion, and decreased thirst, allowing these athletes to perform at higher workloads that those who are

hypohydrated [12, 31]. Athletes who are not euhydrated would miss out on these physiological benefits and would even suffer some detriments.

1.8. Hypohydration on exercise physiology

Hypohydration impairs physiological function during exercise, most notable is cardiovascular function due to an array of issues [32]. Cardiac output decreases in hypohydrated individuals due to decreased blood volume and blood redistribution to cutaneous vascular beds, central pressure, and venous return [5]. Decreases in blood volume from loss of body water or through blood loss[28], with the case of hypohydration being around a 3% loss of body water a decreases in blood volume is extremely likely. Loss of body water lowers both intracellular, extracellular fluid volumes, and results in plasma hypertonicity and plasma hypovolemia, resulting in hypohydration [5]. Hypohydrated individuals have an increase in core temperature especially during sub-maximal exercise due to reduced heat dissipation [5]. For exercising individuals who are hypohydrated they will have increases in heat storage by reduced sweat rates and skin blood flow responses, which results in increased core body temperatures [5]. Endurance athlete who are hypohydrated have higher core temperatures, decreased recovery, higher heart rate, increased feeling of warmth and exertion, increased thirst response, and due to these changes they perform worse than their euhydrated counterparts [12]. Both men and women have higher body temperature, mean blood pressure, and heart rate when exercising without replacing water and becoming hypohydrated during spinning exercises, suggesting that men and women are equally effected by hypohydration [4]. It is also important to remember that heart rate, blood volume, and blood pressure are interlinked together [28], explicating how dehydration can impair cardiovascular function and exercise performance.

1.9. Hydration on performance

Apart from the physiological benefits of being hydrated previously mentioned there are also other benefits to being hydrated when performing exercise [11]. Euhydrated distance runners are better able to pace themselves compared to hypohydrated runners and have faster overall race times [13]. This information is important for distance runners as having an even pace throughout a race leads to better overall finishing times. Euhydrated runners running at maximal pace finished faster, ran at faster paces, and finished with lower core temperatures than those who were hypohydrated [12]. Full fluid replacement during exercise demonstrated a longer time to fatigue than half fluid replacement and no fluid replacement, this implies that individuals who are exercising would benefit from having some type of fluid replacement [30]. Collectively, it appears clear that individuals perform better when hydrated than when hypohydrated.

1.10. Hypohydration on athletic performance

Hypohydration seems to have a minimal impact on some sport-specific skills in such sports as soccer, field hockey, and tennis [11]. Although, hypohydration can have an impact on shooting performance in basketball with decreased shooting accuracy, shot attempts, and longer times to complete sprints [11]. Hypohydrated athletes have reduced ability to complete intermittent running capacity and this detriment may increase during longer duration sports such as soccer [11]. Hypohydrated runners may have a decreased ability to pace themselves through a 12km race [13]. This decreased ability to pace themselves in an endurance event will ultimately lead to and slower overall time as evident by hypohydrated endurance athletes having slower 12-km finishing times during a time trial [12]. When fluid is restricted or an athletes is hypohydrated they will exhibit an accelerated increase in rectal temperature which leads to a reduction in the time to fatigue [30]. Although, when fluid is not restricted, and athletes replace the fluid that is lost through exercise these negative connotations are not observed [4], suggesting that a hydration strategy is important when performing.

1.11. Hydration Strategies

There is a current lack of standardized hydration strategy to mitigate hypohydration and the effects that are associated with hypohydration [33]. Many children cite not enough time for drinking or that drinking is only allowed during breaks as the top reasons for not meeting their hydration needs during practices [7]. However, studies found that a simple fluid replacement strategy on high school football players was effective in the athletes to maintain a euhydrated state [22], showing that a complicated hydration plan is not needed to maintain hydration status. Another intervention of adding around 25 fl oz a day has small but significant improvements on hydration status for Division 3 athletes [6]. Furthermore, it could be argued that hydration strategies should focus on the sport rather than gender to protect athletes and athletic performance [3]. To help with hydration athletes should take part in monitoring their hydration status by weighing themselves before and after practice [34]. Also, athletes can drink water every 15 minutes would prevent a bodyweight loss of 2% based on sweat and sodium loses, although there is a maximum volume to drink to prevent over hydration [33]. Although simple hydration plans work well for large populations, individualized hydration plans, when possible, allow for faster heart rate recovery, improved standing long jump performance, and improved awareness and attention [33].

1.12. Hypohydration in Athletes

College Athletes

As most Division 1 NCAA athletes (66%) were hypohydrated before practice, this population would benefit from better hydration practices to help protect their health and athletic performance [3]. A baseline of 75% of division 3 college athletes from soccer, baseball,

and basketball were also hypohydrated [6]. Similarly, 50% of college cross country runners were dehydrated before a race [35], with the same cross country runners 33% were dehydrated before workouts and 36% were hypohydrated before their recovery runs [35]. Those who start a race severely hypohydrated are at the greatest risk for heat-related illnesses [35]. Although, the reason some runners may be hypohydrated before races is due to the time of the race since if a race is in the morning there may not be enough time to reach a hydrated status, also many runners do not drink before a race to avoid gastrointestinal distress [35]. This epidemic of hypohydration, affects a greater number of male athletes (47%) than female athletes (28%) [3], with this trend being present at the high school level.

High School Athletes

A summer camp of high school athletes observed athletes from various sports being hypohydrated amounting to 74% of all subjects that came to the camp were hypohydrated [7]. Across four days of this camp 56% of football adolescents, 53% of boys' soccer, 38% of girls' soccer, and 39% of football children observed were significant to severely hypohydrated with children at the camp being observed as chronically hypohydrated when entering the camp and throughout the camp [7]. Similarly, another study also observed that almost 90% of the young athletes were hypohydrated [8]. Children from volleyball and basketball teams were hypohydrated with almost both teams entirely hypohydrated before an implementation of a hydration strategy [9]. The hydration strategy resulted in having only 66% on the team hypohydrated [9]. This hydration issue has been observed in a wide-variety of high-school sports, especially those that demand a high level of aerobic endurance and muscular endurance such as Judo [10]. Rivera-Brown and De Felix-Davila [10] found that at the start of Judo training that 21 of the 24 subjects were hypohydrated [10], also over 70% of the subjects reported one or more symptoms of hypohydration and were still hypohydrated at the next training session suggesting a persistent state of hypohydration [10]. Similarly, youth runners appear to be at risk for hypohydration with another researcher highlighting that only about 27% of the youth runners were in euhydrated states [8]. These runners urine specific gravity (USG) on average was classified as hypohydrated from morning, pre-training, and post-training leading to believe that these runners were in a persistent state of hypohydration [8], making evident how important hydration strategies in young athletes are not only to their performance but overall health. Considering these evidences, the use of objective measures of hydration status such as urine specific gravity are of unparallel importance to ensure the health and safety of young athletes.

1.13. Measures of Hydration

Plasma Osmolality

Plasma osmolality is often considered the gold standard of hydration status [22]. Walsh, Laing [36] found that after 2% body mass lost from dehydration that plasma osmolality

was significantly greater than pre-exercise levels. Oppliger, Magnes [37] observed that plasma osmolality increased significantly through each stage of their protocol and peaked out at 5% dehydration. Plasma osmolality is the best method for assessing hydration status and is sensitive to small changes in hydration although it lacks feasibility in the field due to equipment needs, cost, and compliance with blood sampling protocols [37].

Urine Specific Gravity

Urine specific gravity is a measure of urine density, which is the weight of urine compared to an equal volume of distilled water [32]. Hydration status is typically divided into three categories when using urine specific gravity (USG) and has been used previously [3, 6]. The three USG categories are euhydrated is 1.000 to 1.020 USG, hypohydrated is 1.021 to 1.029 USG, and significantly hypohydrated is 1.030 or greater USG. Normal urine ranges from 1.013 to 1.029 with 1.000 being equal to plain water [32]. Urine specific gravity is a simple and valid field measure as taking blood in the field is not always practical and can be expensive [3]. USG has a low inter-individual variability compared with urine osmolality measurements [32]. One disadvantage of USG is that it does not assess acute changes in dehydration as well as plasma osmolarity [3].

Salivary Measures

Strong relationships are observed between plasma osmolality and saliva osmolality and a strong relationship between plasma osmolality and saliva total protein concentration ($r = 0.91$) and reflect changes in hydration status [36]. Saliva osmolality, saliva total protein concentration and urine osmolality appear to have a higher sensitivity to changes in hydration status than saliva flow rate [36]. An increase in extracellular sodium concentration during hypertonic-hypovolemia might result in the production of smaller amounts of more concentrated saliva [36]. Although, saliva total protein concentration appears to be more sensitive to changes in whole body hydration status during acute dehydration than saliva flow rate [38]. Euhydration determine by saliva total protein concentration may be 0.55-0.95 mg/ml and by saliva osmolality with 41-61 mOs mol/kg [38].

Body Mass

Using body weight changes is one of the simplest methods for assessing water loss during physical exercise for a short period of time [32]. Change in body mass can be used as an index of a change in hydration status [39]. This measure is easily done and requires no technical expertise [32]. Body mass is a reliable and simple measure to administer that provides accurate and timely information about fluid loss and hydration status [40]. Although changes in body weight can come from other sources besides hydration status and makes this parameter unusable for long duration studies [32]. Logan-Sprenger, Heigenhauser [31] observed that their hydration group was able to maintain body weight after exercise whereas their hypohydration

group had a significantly lower body mass supporting this as a measure of acute changes in hydration status after exercising.

Sweat Rate

Sweat contains primarily sodium, chloride, potassium, calcium, magnesium, and is hypotonic to extracellular fluid [5]. Gravimetric techniques of measuring sweat rate such as absorbent patches involve collecting sweat from the surface of the skin and is more practical in field testing than other techniques such as hygrometry [41]. Although there are some limitations when using gravimetric techniques such as they can change the flow rate of sweat on the skin surface due to changing the local environment and limiting ventilation [41]. Sweat rate is also used to help monitor if athletes are replacing fluid equal to what they loss through sweat during exercise and is used in may sports such as basketball to monitor fluid loss [41, 42].

RPE/Heart Rate

Heart rate variability (HRV) is used to assess an athlete's physiological status and indicates the variation in beat-to-beat intervals [43]. When an athlete is hypohydrated their heart rate variance is reduced and should be considered when using HRV to determine physiological status [43]. Logan-Sprenger, Heigenhauser [31] found that heart rate was significantly higher in their hypohydration group versus their hydration group and that RPE was high in the hypohydration group versus the euhydration group supporting that hypohydration has effects of physiology. Temperature and cardiovascular centers may sense the elevation in core temp, heart rate, and reduced plasma volumes to the brain and thus increasing the RPE during exercise at the same intensity in a hypohydrated state [31]. RPE has been shown to increase as hypohydration status becomes more severe [12, 31], making RPE a possible way to monitor possible hypohydration in athletes.

Sleep and Cortisol

Sleep has been shown to have adverse effects on performance in exercise last longer than 30 minutes [44, 45]. Oliver, Costa [45] found that their participants covered less distance during a distance test after sleep deprivation, although sleep deprivation did not seem to affect the participants pace. The limited effect of sleep deprivation observed on cardio-respiratory and thermoregulatory function, which lead them to suggest that the decrease in distance cover may have been due to altered perception in effort [45]. Partial sleep deprivation may also cause an increase in cardiac and peripheral sympathetic modulation as well as heart rate and blood pressure variability [46]. Fullagar, Skorski [44] also found that sleep deprivation was detrimental to endurance and repeated exercise but found that sleep restriction had conflicting results on performance only stating that generally maximal one-time efforts were maintained. Athletes tend to have poorer quality of sleep compared to non-athletes but still stay within the range of healthy sleep [47]. Although, male athletes stay in bed longer to obtain

similar sleep time as female athletes suggesting that male athletes have lower sleep efficiency [47]. Although there seems to be a wealth of knowledge on poor sleep impairing performance Thun, Bjorvatn [48] suggest that a night of poor sleep may not always be detrimental to performance, but did go on to say a good night's sleep is an important factor for athletes to perform their best. Sleep as has some connections to hydration in which short sleep durations, compared to the normal 8 hours, being associated with adults having higher odds of inadequate fluid intake [49]. Contrary to this evidence Halson [50] noted that many athletes having sleep disturbances due to waking up to urinate possibly due to rehydration or hyperhydration. Circadian rhythms were suggested to be a main regulator in exercise cortisol, as exercise salivary cortisol levels are primarily dependent on baseline levels, which in turn is manly regulated by circadian rhythms [51]. Cortisol is stress hormone that mediates catabolic functions [52]. Cortisol was found to be higher in the morning vs. the evening, but induced cortisol response was greater in the evening than the morning [51]. The best time of day to train is during the evening as there is when the immunosuppressive effect is the lowest [51]. Higher training loads were significantly correlated with higher salivary cortisol concentrations and would be a good non-invasive way to monitor overtraining in elite athletes [53]. There is also evidence that female distance runners produce overall higher levels of cortisol to stress [54]. In contrast, Buchheit, Racinais [52] found that cortisol did not correlate well with changes in daily training loads or high-intensity interval performance.

Chapter 2. Purpose

A problem that is seen when exercising in the heat is keeping athletes euhydrated by maintaining fluid balance. A person can dehydrate during exercise due to not having fluid available or due to their thirst not matching the amount of fluids they require. Euhydrated is defined as normal body-water content [3]. Hypohydration is a body water deficit and hyperhydration is an increased body water content [5]. Dehydration is the process of reducing total body water going from euhydrated to hypohydrated [5]. There are methodological considerations when testing for hydrations status influence on performance such as crossover design, weather conditions, exercise intensity as athletes may lower than intensity when dehydrated [12]. Hypohydrated runners experienced more physiologic strain than hydrated runners and that the hypohydrated runners had to work harder to accomplish a task [12]. Typically if rehydration isn't force then marked hypohydration will occur when exercising in the heat [5]. Simple fluid replacement strategy on high school football players was effective in athletes maintaining a euhydrated state [22]. The purpose of this study is 1) to determine if high school cross country athletes are at risk for becoming hypohydrated from practice and 2) if a hydration strategy can offset this hypohydrated status and improve performance. We hypothesize that the high school cross country runners will be at risk for hypohydration and that with a simple hydration strategy they will maintain a euhydrated status and improve their 3-mile time trial performance.

SA1: Determine whether high school cross country runners may be at risk for hypohydration during in-season training.

Hypothesis: We hypothesis that this population is at risk for hypohydration during in-season training.

To test this hypothesis, we tested these athlete's hydration status under their normal training conditions before and after a 5K time trial. Furthermore, we correlated their running time with pre- and post-exercise hydration status.

SA2: Characterize the impact of increasing hydration level on performance and exercise-induced hypohydration.

Hypothesis: We hypothesis that increasing hydration levels will be associated with improvements in performance (5K time trial) and cognitive function in high school cross-country runners.

To test this hypothesis, we implemented a simple hydration strategy and test hydration status before and after a 5K time trail and compare these to baseline measures.

The primary objective of this project was to determine if high school cross country runners are at risk for hypohydration. We hypothesize that this population is at risk for being hypohydrated

and would benefit from a hydration strategy. The secondary objective of this project was to determine if there are effects of euhydration on performance and exercise-induced hypohydration. We hypothesize that being euhydrated will lead to better performance on a 5K time trial versus being dehydrated.

Chapter 3. Methods

To test for these objectives, we tested both male and female high school cross-country runners on urine specific gravity, sweat, salivary enzymes, heart rate, core temperatures, body mass, psychological questionnaire, and a time trial. We also had a weather station to monitor the weather conditions on days of testing and we collected the temperature of the running surface. During both weeks of testing we asked the participants to perform a 3-mile time trial on Monday and Fridays. We provided water after each practice on Monday and Friday to monitor the volume of water intake by the athletes. A subset of the subject population (10 athletes) was asked to wear a watch to monitor sleep and activity for the duration of the study (12 days total). The first week of testing was used to establish baseline as was the first day of testing on the second week. The testing days occurred on Monday, Wednesday, and Friday on each week. Wednesday was used to collect weight and hand out questionnaires no other measurements were taken on this day. On Friday we had the athletes swallow a core temperature pill to acquire pre and post core temps. We collected pre-practice samples of urine, saliva, weight, environmental temperature, core temperatures, and psychological questionnaires. We also took post-practice samples of all previously mentioned measurements and sweat, rate of percieved exertion, and heart rate measurements were taken during practice. The participants toweled dried before post-practice weighing. The first week of testing there was no intervention, and this was used to have a baseline measure to use as a control. The participants followed their normal practice schedules as prescribed by their coach. During the second week of testing we implemented a hydration strategy and had the participants take a 32 oz. cup with them and drink a full 32 oz. with their breakfast and dinner. We then let the participants return to their normal hydration strategies and had one more testing day. The participants were given t-shirts for their participation in the study.

3.1. Participants

We recruited high school cross country runners to volunteer for this study. We excluded any runners who are not in high school as some schools do allow middle school runner to participate at the high school level. We tested both male and female runners and attempted to have an equal number of males and females participating in the study. The participants were active high school runners who were free of injury and who passed the high school's physical exam. The participants were in top condition as they were training for their state meet this controlled for most of the training effects that occurred during the beginning of the season. The participants also were acclimatized to hot-wet environments as they are accustomed to south Louisiana environment.

3.2. Study Design

The study took place over a two-week period with testing occurring on Monday and Friday after school during normal practice hours. On Wednesdays during the athletes first hours with the school's permission we weighed them and give out questionnaires for the

athletes to complete. The first week of testing was the non-intervention week, using Monday as a baseline testing with Friday being a testing day of normal hydration practices by the athletes. The second week of testing included a hydration strategy, implemented on Wednesday. The hydration strategy had the athletes to take home a 32 oz. water bottle and drink one bottle with breakfast and dinner until testing day on Friday. Monday of the second week will be baseline testing with Friday being the testing day for the hydration strategy to determine if the hydration strategy worked and if there was an effect on the athlete's performance.

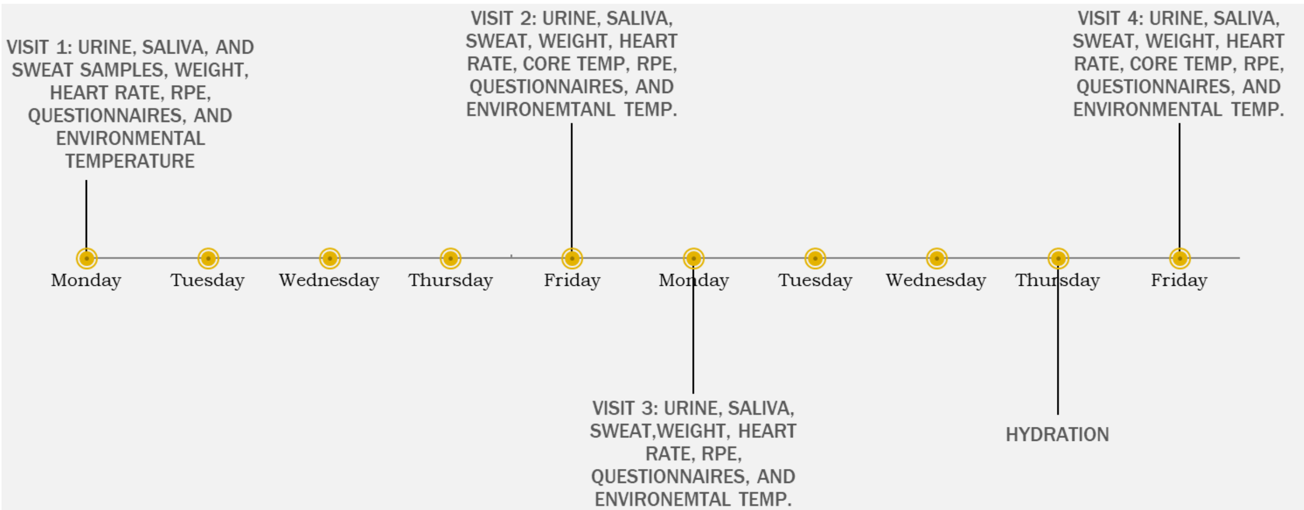

Figure 1. Study Design

3.3. Anthropometric

The athlete's height, weight, and age were taken on the first day in the morning. Weight was also taken before practice after the athletes urinate and after practice after the athletes have toweled dried. Body weight was used to determine the amount of body weight lost due to sweating which was used to determine the percent of body weight lost due to water lose.

3.4. Training Protocol

The athletes followed their normal training schedule prescribed by the coach. We asked the coach to provide us with their training menu, which allowed us to time their training sessions. We also had the athletes perform a time trial on the Fridays of both weeks.

3.5. Performance

Performance was determined by the athlete's performance on a 3-mile time trial through the team's normal training grounds so that the athletes were familiar with the route. We will time the athletes using a stop watch and the athletes were encouraged to perform their best for the time trials.

3.6. Urine Specific Gravity

Urine was collected from the athletes before practice and after practice. Urine was collected in a cup by the participants and then urine specific gravity (USG) was determined. The urine was aliquoted into 1.5ml tubes and analyzed in the lab. Urine specific gravity was tested on site after the urine was collected, we will use urine refractometer to determine urine specific gravity. The urine refractometer was calibrated using pure water each day before collection. The urine specific gravity determined the hydration status of the participants, the three USG categories are euhydrated is 1.000 to 1.020 USG, hypohydrated is 1.021 to 1.029 USG, and significantly hypohydrated is 1.030 or greater USG. The 1.5ml aliquots of urine were analyzed for electrolyte content of sodium, potassium, and chlorine.

3.7. Salivary Measures

We collected saliva using salivette tubes before and after practice. The athletes were asked to put the collection cotton under their tongues for 4 minutes, after 4 minutes the cotton was placed back in the tubes and stored until further analyzed. The collect of saliva samples was done with the participants all together as to have the samples collected at the same time and to make sure that the collection cotton is only in their mouths for 4 minutes. The saliva was analyzed for total protein content, salivary flow rate, and cortisol content. The total protein content and salivary flow rate was used to check participants hydration status. Cortisol content was used to determine hydration, stress, and if it had an association with sleep patterns of the participants.

3.8. Sweat Rate

Sweat patches was put onto the participants immediately before they began practice and taken off immediately after they finish practice as to have their practice time be the time that the sweat patch was on to determine sweat rate. The sweat patches were made with cotton stuck onto a piece of parafilm, which will then be taped to the small of their back on their right side. This design allowed for the cotton to collect sweat and not come off during practice. The cotton for the sweat patches was weighed before being used and after to determine the volume of sweat collected. The sweat patch was then centrifuged to separate the sweat from the cotton and then the sweat was analyzed to determine the sodium, potassium, and chlorine in the sweat.

3.9. Heart Rate

Heart rate was taken in the morning of the first testing day to get an accurate resting heart rate. Heart rate was collected using the radial artery counting the heart beats for 30 seconds then multiply that number by 2. Heart rate was taken before practice although as the students were in school it will be hard to collect a true resting heart rate without interfering with the coach's practice. Heart rate was taken immediately after practice again using the radial artery for a 30 second period. Heart rate was used to determine the intensity of the time trials

and the practices. This measure was important for the time trials to ensure that the participants were running at a high intensity and fully exerting themselves.

3.10. Sleep

We monitored sleep throughout the entire study using actigraph watches. Using the Acitwatch2 the athletes were these watches throughout the entire study to collect sleep as well as activity. We had 10 participants wear the Actiwatch2 5 female and 5 male and these watches were assigned to that participant through the Actiwatch2 software. The data was collected and processed through the Actiwatch2 software. The data was used in conjunction with a sleep quality questionnaire to determine sleep quantity, quality, and patterns for the duration of the study. This data was used to determine if sleep has an impact on performance and cortisol concentrations. This sleep data was also used with a life demands questionnaire that monitors sports demands to determine if there was a correlation between amount/quality of sleep and sports demands such as muscle pain, recovery time, and sports training.

3.11. Core Temperature

We collected core temperature on the two testing days for the study. We had the participants take the core temperature pills in the morning of testing days (6 hours before testing) where they were given a "NO MRI" band for medical purposes should an accident occur while the core temperature pill was still within the athletes. We used HQInc. core temperature pills and took core temperatures before and after the 3-mile time trial using a wireless sensing device. Core temperatures were used to see associations between hydration status and performance and if hydration status significantly effects core temperatures. Core temperatures were used in correlation with the upper respiratory symptom survey to determine if a participant with cold symptoms had increased core temperatures before practice that will affect the outcome of performance and post core temperature.

3.12. Questionnaire

Pittsburgh Sleep Quality Index

The Pittsburgh Sleep Quality Index (PSQI) is used to measure quality and patterns of sleep for the past month [55]. The PSQI inquiries about the participants normal sleep pattern, sleep medication, trouble staying awake during the day, and overall sleep quality. In this study the PSQI was used daily with participants taking the questionnaire every morning to determine their quality of sleep for the night before. This data was used in conjunction with data from the Acitwatch2 to better determine the athlete's quality, quantity, and pattern of sleep throughout the study.

Daily Analysis of Life Demands

The Daily Analysis of Life Demands (DALDA) measures general wellbeing as well as sports/activity wellbeing [56]. The DALDA is a reliable measure of changes in stress

and recovery states of athletes [56]. The DALDA asks general questions of daily life such as diet, school, and friends as well as sports/activity daily life like muscle pains, techniques, and recovery time. These questions are answered with “worse than normal”, “normal”, and “better than normal”.

Activation-Deactivation Adjective Checklist

The Activation-Deactivation Adjective Checklist (AD-ACL) is a questionnaire that uses adjectives for individuals to grade how the adjective currently describes themselves [57]. Some of the adjectives used are energetic, tired, fearful, quiet, and tense. The individual is asked to grade these adjectives using “definitely feel”, “feel slightly”, “cannot decide”, and “definitely do not feel”. This was used to better understand how the participants feel on a day to day basis throughout the study.

Wisconsin Upper Respiratory Symptoms Survey

The Wisconsin Upper Respiratory Symptoms Survey (WURSS-21) measures an individual’s cold symptoms and if it interferes with daily tasks. The WURSS-21 is a valid measures of cold symptoms with the same performance as the WURSS-44 [58]. The questionnaire asks basic cold symptoms such as runny nose, sore throat, and cough along with if these symptoms interfere with thinking clearly, breathe easily, and work inside the home. The participants are asked to grade the symptoms and interference from 0 to 7 with 0 being “not at all” and 7 being “severely”. This data was used in conjunction with performance data as well as salivary data to determine if illness was a factor in the outcomes of the other measures.

3.13. Environmental Conditions

We recorded the environmental condition before, during, and after the practices. We will take surface temperatures using an infrared thermometer. We took environmental temperature, wind speed, and wind chill using Kestrel systems to monitor these conditions while the athletes practice this data was collected every 30 seconds. This data as important in monitoring the environment as hot-dry and hot-wet environments have different effects on the human body during exercise. This was important in performance and core temperature outcomes as weather can be unpredictable this helped account for the effect of the weather as much as possible.

3.14. Statistical Analysis

All data was assessed for assumption of normality using the Shapiro-Wilk test prior to subsequent formal statistical testing. We used the Shapiro-Wilk test as it is one of the most powerful normality tests[59]. Skewed data was transformed for standardized testing. A 2-

way repeated-measures analysis of variance with post hoc t test was used to determine the relationships between performance and hydration. A one-way ANOVA with pair student t tests was used to determine significant changes of measurements between days. We used a multivariate multiple regression analysis and looked at measures and find the least squares regression line to find relationships and interactions between the multiple measures taken. All statistical analysis was performed with JMP Pro 14.

Chapter 4. Results

The study collected data over a period of two weeks to test hydration status of high school cross-country runners. Athletes were instructed to maintain their normal hydration status during the first week of the study (hypohydration period), while a simple hydration strategy was implemented during the second week of the study (hydration period). The first week was referred to as the hypohydration group and the second week was referred to as the hydration group as week two had a hydration plan implemented. The first week included a baseline test (visit 1) and a time trial (visit 2), during the second week there was another baseline test (visit 3) then a hydration plan was implemented between the baseline (visit 3) and another time trial (visit 4) to determine the effects the hydration plan had on hydration measures as well as performance in the time trial. A 3-mile run was performed during practice to evaluate performance during the study.

4.1. Participants Characteristics

A total of 15 participants took part in the study, however 1 participant did not finish the second week of the study due to other sport commitments. The participants anthropometric data is provided below in Table 1. Body surface area (BSA) was calculated using the participants day 1 height and weight. There were no significant differences in participants characteristics.

Table 1. Age, Height, Weight, and Body Surface Area of participants.

Measurements	All participants (n=15)	Male (n=9)	Female (n=6)
Age (year)	15.53 ± 1.15	15.33 ± 1.12	15.83 ± 1.33
Body Mass (kg)	58.57 ± 11.18	59.89 ± 13.52	56.58 ± 7.02
Height (cm)	168.91 ± 8.61	172.36 ± 9.08	164.08 ± 4.78
BSA (cm^2)	16525 ± 1472.60	16771.43 ± 1745.78	16180 ± 856.51

4.2. Baseline Result for Hydrated and Hypohydrated Groups

Hydration status was analyzed using pre-practice USG of the baseline days for the hypohydration group (visit 1) and the hydration group (visit 3) to determine if the baseline days were different or determine if they were true baseline days having similar results. Comparing the two baseline days against hydration and performance measurements to determine if there was a significant difference between these baseline days. No significant difference was found between pre-practice USG for baseline days ($p = 0.6177$) seen in Figure 2. Post-practice USG also had no significant difference between the two baseline days ($p = 0.2798$), both measures suggesting that hydration status was equal on both baseline days. Race time was significantly different between the baseline days with visit 3 (hydration baseline) being significantly faster than visit 1 (hypohydration baseline, $p = 0.0075$) seen in Figure 3. Additionally, a significant

effect of gender was observed on performance (race time; p = 0.0081) with males having faster race times then females present in Figure 4, but not on other baseline measurements.

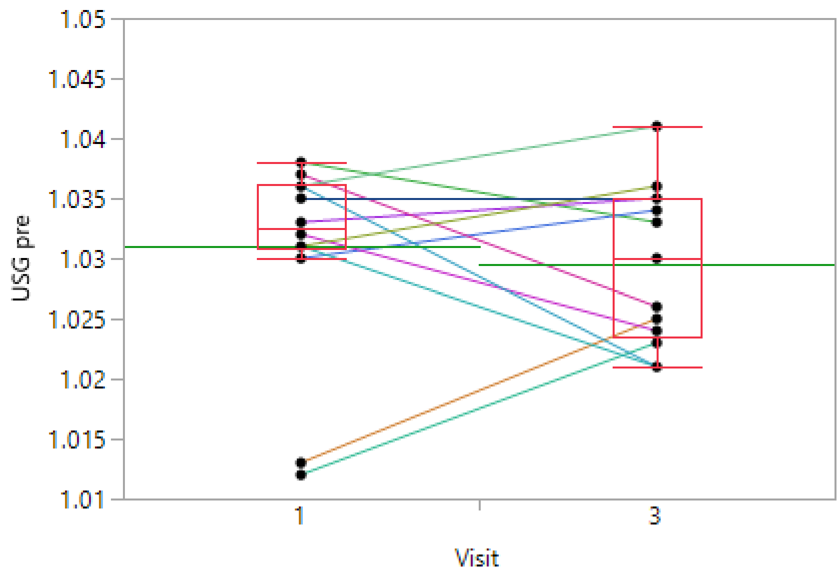

Figure 2. Pre-Practice Hydration Status for Baseline Days.

All individual pre-practice USG data points with box plots and mean line (Green) for each baseline day. p = 0.6177.

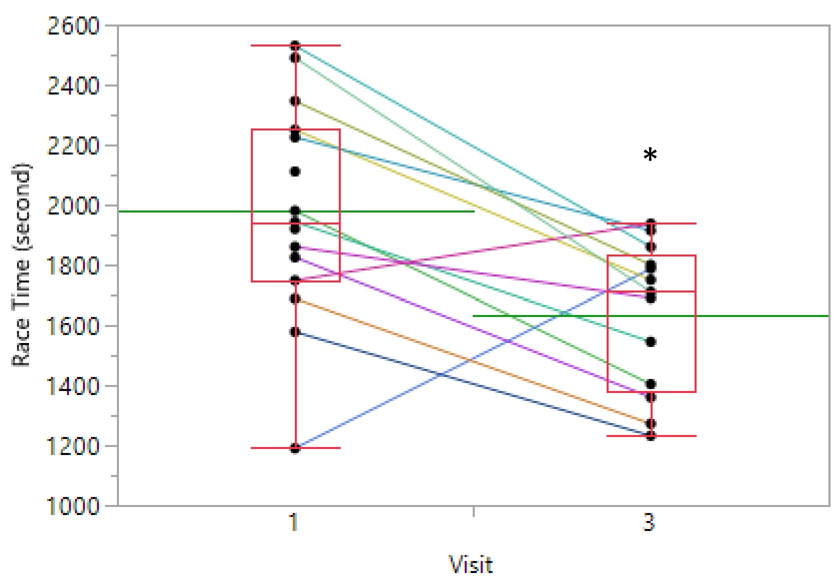

Figure 3. Baseline Race Times.

All individuals race times with box plots and mean line (Green) for each baseline day. * corresponds to a p<0.05.

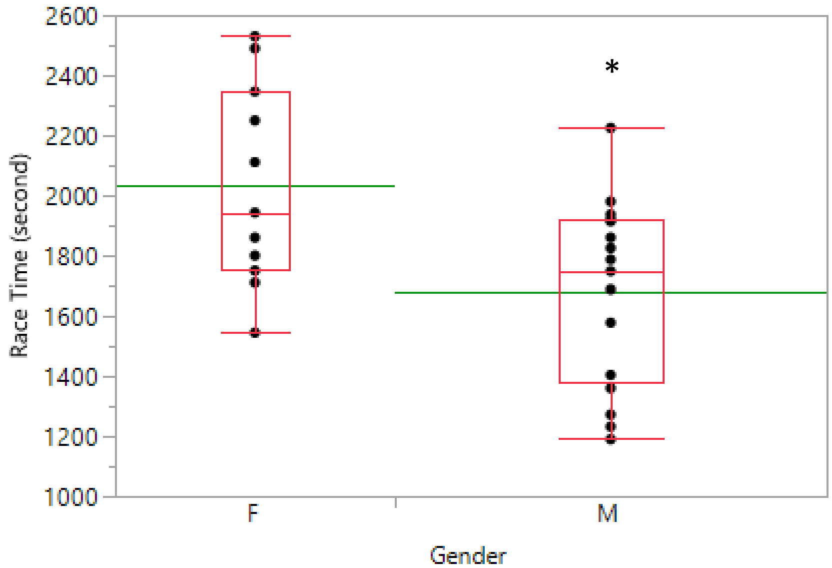

Figure 4. Gender Effect on Baseline Race Times.

Race times by gender with box plots and mean line (Green) for each gender. * corresponds to a p<0.05.

4.3. Hydrated Time Trials vs. Hypohydrated Time Trials

Hydration status as well as time trial performance was analyzed using the two time trial days to find the difference between the hypohydration time trial (visit 2) and the hydration time trial (visit 4) and to determine if our hydration plan had any effect on hydration status and performance. Analyzing the two time trial days pre-practice USG using a one-way ANOVA we found that visit 4 (hydration test) had a significantly lower pre-practice USG value ($p = 0.0006$), which can be viewed in Figure 5. Post-practice USG was not significantly different between the two days ($p = 0.0946$), although there was a large change in the means between the two day ($\Delta = 0.006$), represented in Figure 6.

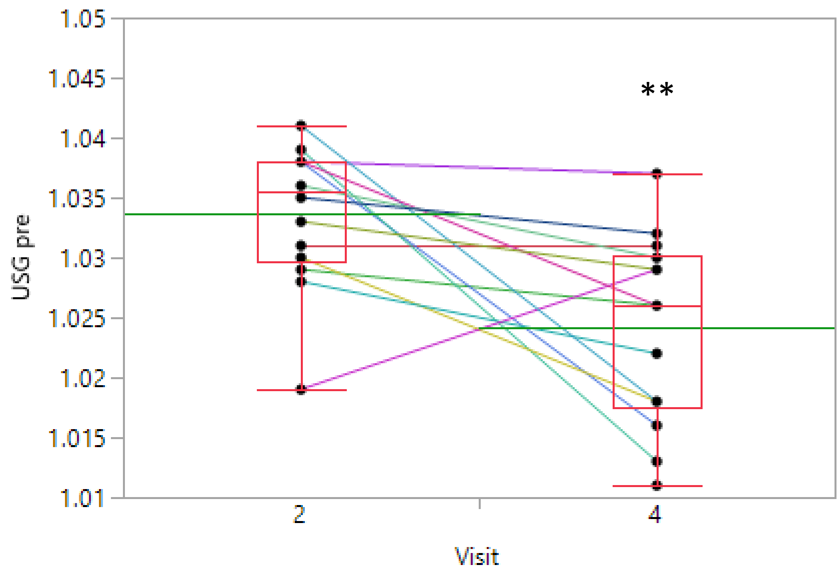

Figure 5. Impact of Hydration Strategy on Pre-Practice USG

Pre-practice USG data points with box plots and mean lines (Green) for each time trial. ** corresponds to a p<0.001.

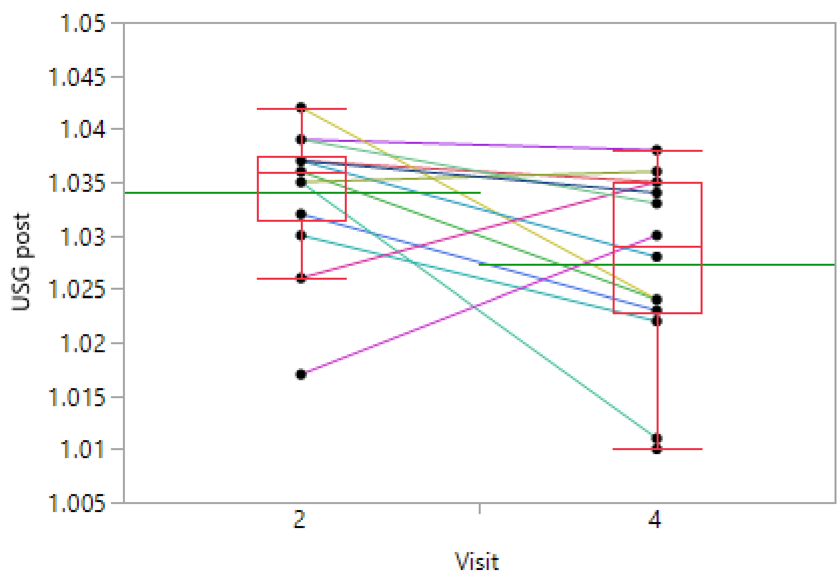

Figure 6. Impact of Hydration Strategy on Post-Practice USG

Data points for post-practice USG with mean lines (Green) for each time trial with mean to mean trend line (Blue). p = 0.0946

Surprisingly, there was not a significant difference in race time between the two days (p = 0.1938) according to absolute race times. Interestingly, there was also no significant difference in post-practice heart rate (p = 0.1206) suggesting that the athletes were running around the same intensity for both time trials. Even though absolute pre-practice USG was significantly lower in visit 4 (hydration test) there was no significant difference in absolute race time between the two days. However, analyzing the change in pre-practice USG to the change in race time from visit 2 to visit 4, there was a significant change (p = 0.0209) and a strong correlation of 0.63 observed, which is presented in Figure 7. A significant difference was also seen in race time between genders (p = 0.0305) with males having faster race times than females seen in Figure 8.

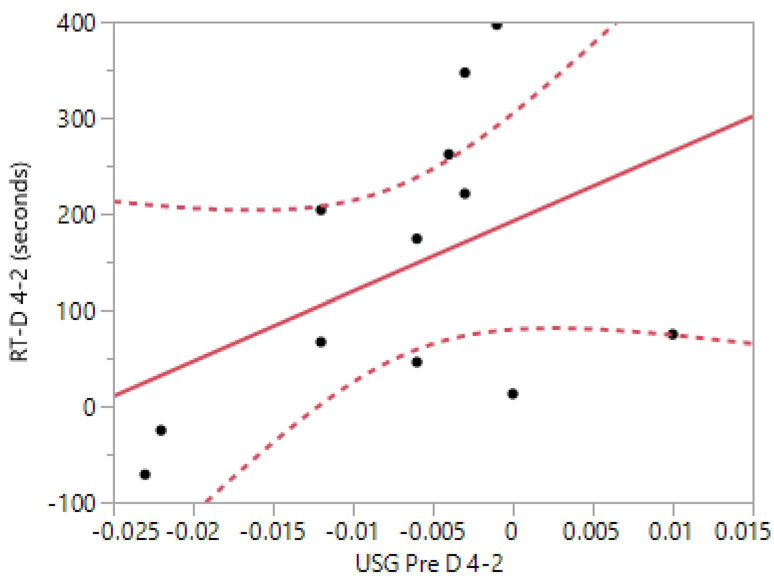

Figure 7. Impact of Hydration Status on Time Trial Performance.

Difference in pre-practice USG from visit 2 to visit 4 with negative change indicating a lower pre-practice USG on visit 4 compared to difference in race time between time trials with a negative change indicating a faster time on visit 4 with trend line (Red line) and 95% confidence lines (dotted line). p-value = 0.0209.

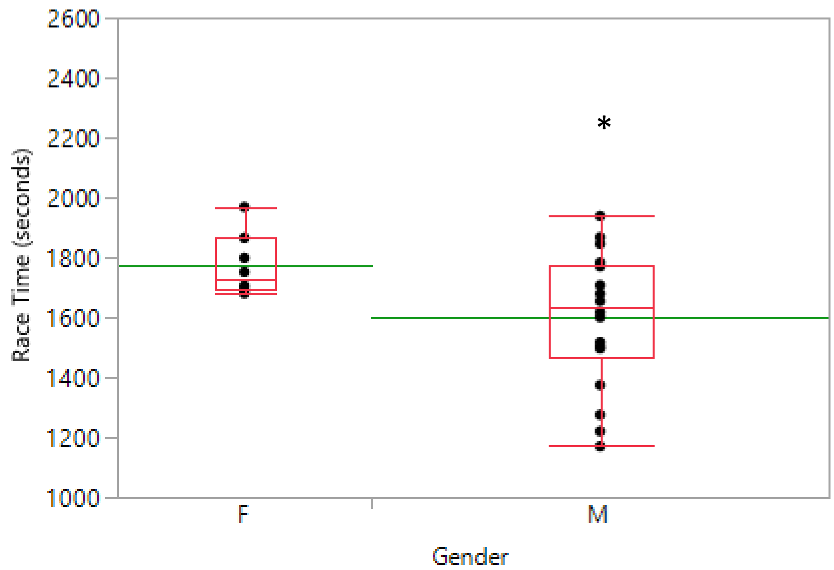

Figure 8. Gender Effect on Time Trial Performance.

Race time for the two-time trials by gender with box plots and mean line (Green). * corresponds to a $p<0.05$.

No significant differences were found between visit 2 and visit 4 pre-practice and post-practice core temperatures (p = 0.8662, p = 0.1647 respectively). However, a significant difference was observed in the change in core temperature from pre-practice to post-practice between visit 2 and visit 4 (p = 0.0351) seen in Figure 9, with visit 2 (hypohydration test) having significantly lower changes in core temperature despite having higher pre and post practice USG values. When core temperature was compared with race times there was no significant effect of post-practice core temperature (p = 0.1896) but had a weak correlation of 0.28. When the change of core temperature from pre-practice to post-practice was compared to race times there was no significant effect (p = 0.0799), although there was a moderate correlation of 0.37. Analyzing the difference between post-practice core temperature from visit 2 to visit 4, to the difference in race time from visit 2 to visit 4 we found that it was not a significant effect (p = 0.3163), but there was a moderate correlation of 0.38. Lastly, we found that total body sweat rate (ml/min) across the two time trial days were not significantly different (p = 0.4369) seen in Figure 10.

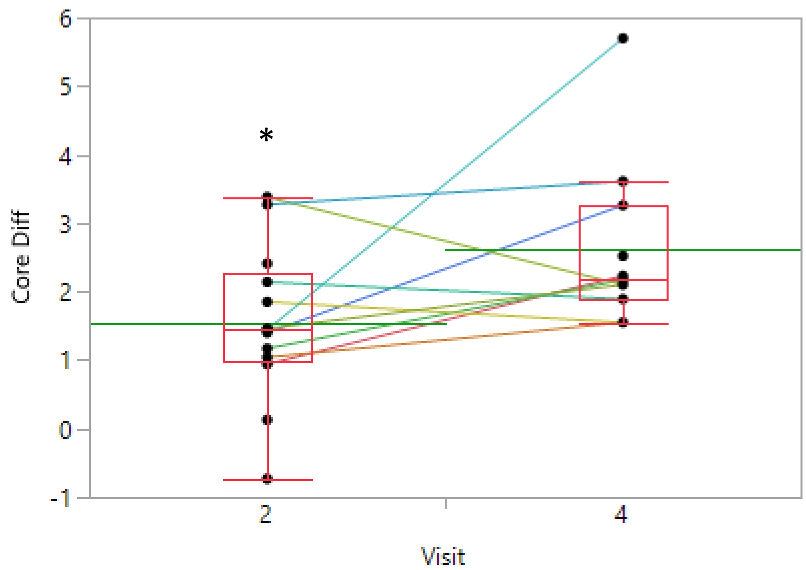

Figure 9. Effect of Hydration Strategy on Core Temperature.

Change in pre to post core temperature for each individual for each time trial with box plots and mean line (Green) for each time trial. * corresponds to a p<0.05.

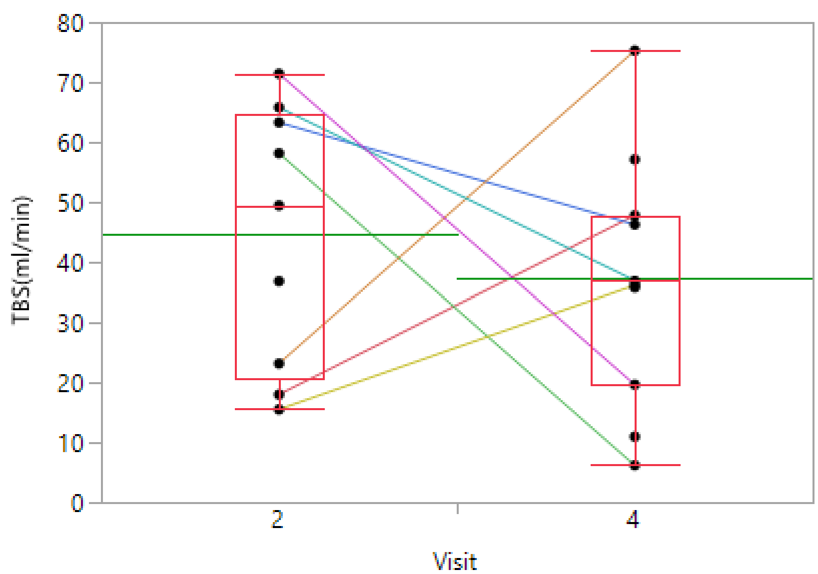

Figure 10. Impact of Hydration on Total Body Sweat Rate (ml/min).

Total body sweat rate for each individual by time trial with box plots and mean line (Green) for each time trial. p = 0.4369.

4.4. Hydration, Performance, and Related Measurements

After analyzing the baseline and testing days separately, the next step was to analyze all the days together and compare hydration measurement to questionnaires. The results of pre-practice USG across the 4 testing days in present in Table 2 and Figure 11. There was a significant difference in pre-practice USG from visit 2 and visit 4 ($p=0.0005$). Visit 1 and visit 4 also had a significant difference ($p=0.0146$), although as expected visit 1 and 3 were not significantly different. Surprisingly with the hydration plan visit 3 and visit 4 were not significantly different ($p=0.0565$), although there is a downward trend of pre-practice USG lowering across visit 3 to visit 4. Through a 2-way repeated measures ANOVA there was no significant effects, expect for group over time which is represented in Figure 11.

Table 2. Pre-Practice USG Data for Each Data Collection Day.

Visit	Mean	Std Error	Lower 95%	Upper 95%
1	1.031	0.00192	1.027	1.035
2	1.034	0.00185	1.030	1.038
3	1.030	0.00199	1.026	1.034
4	1.024	0.00192	1.020	1.028

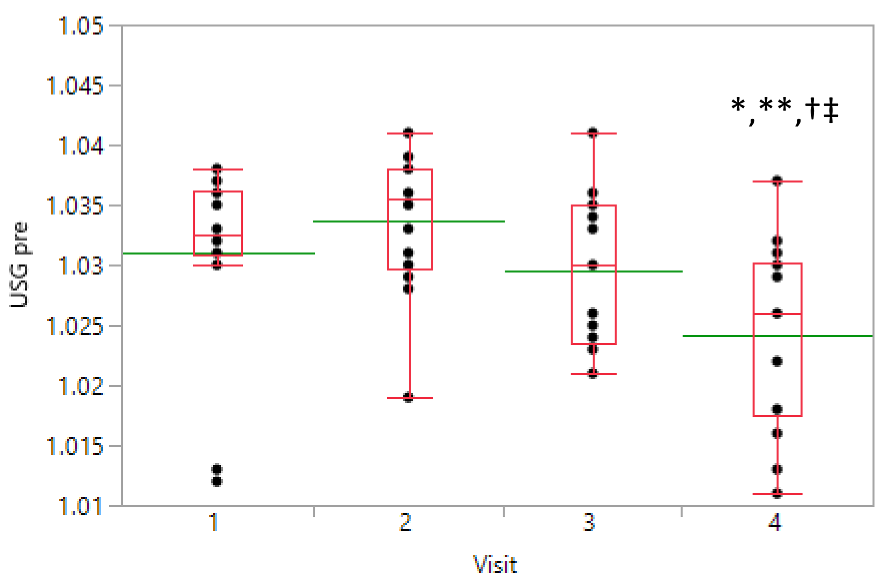

Figure 11. Changes in Pre-Practice Hydration Status.

Pre-practice USG data for each day of data collection with box plots and mean line (Green) for each visit. † corresponds to a significant difference from visit 1, ‡ corresponds to a significant difference from visit 2, * corresponds to p<0.05, ** corresponds to p<0.001.

Although there were no significant effects (p = 0.1886) of questionnaires on pre-practice USG there was a small positive correlation (correlation = 0.23) between PSQI and pre-practice USG. The results for post-practice USG across the 4 testing days are presented in Table 3 and Figure 12. A significant change in post-practice USG from visit 1 to visit 4 (p = 0.0214), which was the only significant change between days of testing. Visit 2 to visit 4 was the next closest significant difference (p = 0.0651). Pre-practice USG compared to post-practice USG showed that a lower pre-practice USG was associated with a lower post-practice USG (P = 0.0001), this relationship is presented in Figure 13, there was no significant difference between each day for this relationship.

Table 3. Post-Practice USG Across Each Data Collection Day

Visit	Mean	Std Error	Lower 95%	Upper 95%
1	1.034	0.00215	1.030	1.039
2	1.033	0.00201	1.029	1.037
3	1.031	0.00215	1.027	1.036
4	1.027	0.00208	1.023	1.032

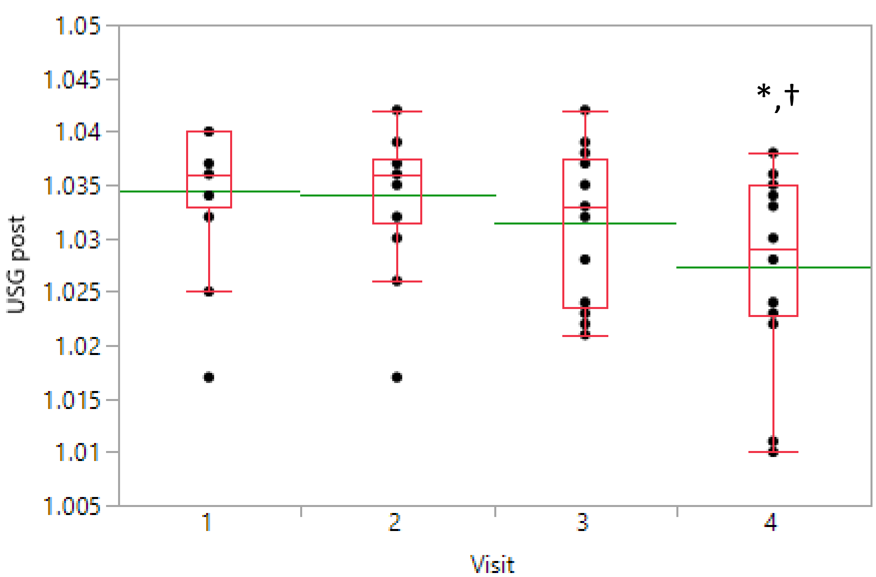

Figure 12. Changes in Post-Practice Hydration Status.

Post-practice USG for each individual across each data collection day with box plots and mean line (Green) for each visit. * corresponds to a p<0.05, † corresponds to a significant difference from visit 1.

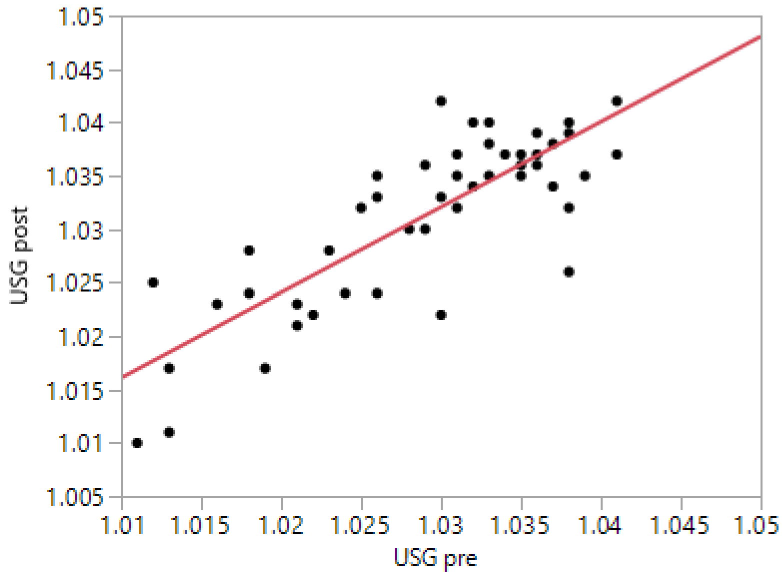

Figure 13. Pre-Practice Hydration Status Effect on Post-Practice Hydration Status.

All USG data points for each individual comparing pre-practice USG to post-practice USG with trend line (Red line). p = 0.0001.

Race times across the 4 testing days is presented in Table 4 and Figure 14. Visit 1 was significantly different than all other days (1vs2 p = 0.0004, 1vs3 p = 0.0012, 1vs4 p = 0.0112). There were no other significantly different race times between visit. When race time is compared to pre-USG across each data collection day there is no significant effect (p = 0.9795) and relatively no correlation (-0.003) between the two measurements, which is represented in Figure 15. Although pre-practice USG did not influence race time there was a significant effect (p = 0.0209) of pre-practice USG change between visit 2 and visit 4 when compared to change in race times between visit 2 and visit 4 (correlation = 0.63), previously represented in Figure 7.

Table 4. Race time for each day of Data Collection.

Visit	Mean (sec.)	Std Error	Lower 95%	Upper 95%
1	1978.92	68.08	1842.3	2115.50
2	1613.27	68.08	1476.7	1749.90
3	1635.46	73.13	1488.7	1782.20

4	1716.15	73.13	1569.4	1862.90

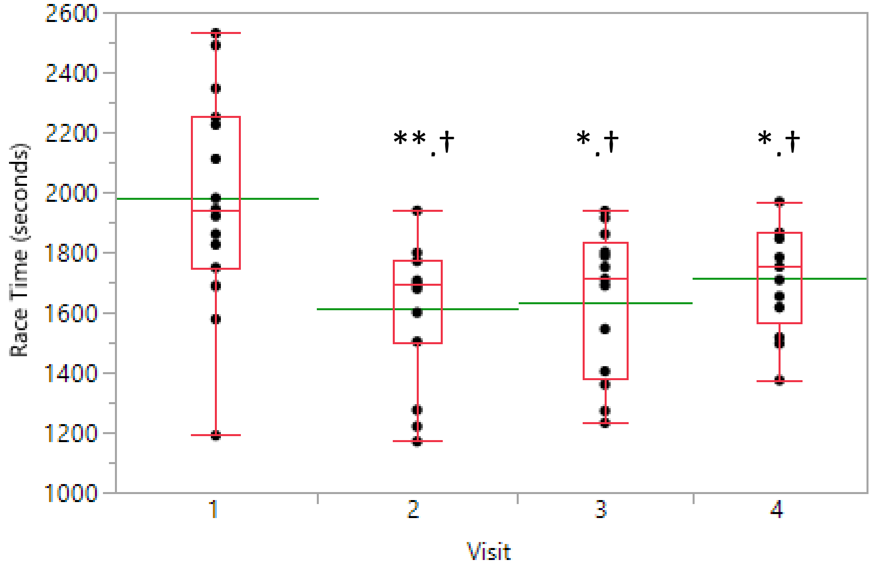

Figure 14. Changes in Race Time.

Race times for each individual across each data collection day with box plots and mean lines (Green) for each visit. * corresponds to p<0.05, ** corresponds to p<0.001, † corresponds to significant difference from visit 1.

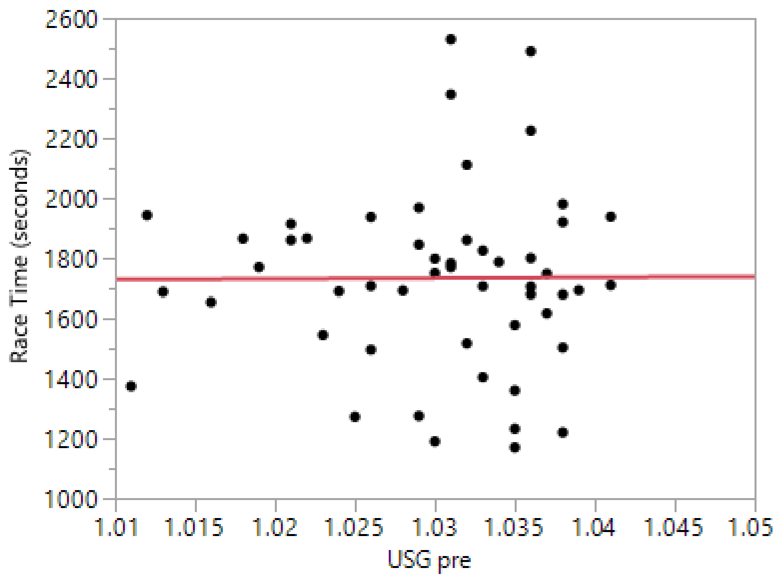

Figure 15. Pre-Practice Hydration Status Effect on Race Times.

Total pre-practice USG for each individual across each data collection day compared to race times for each individual across each data collection day with trend line (Red). p = 0.9795.

There were no significant relationships between race time and questionnaires, although there were interesting trends between race times and the scores of the questionnaires. The WURSS questionnaire had a negative relationship (correlation = -0.11, p = 0.5305) with race times with higher WURSS scores trending to faster race times. There was also a significant difference between genders on WURSS scores (p = 0.0307) with females having significantly lower scores than males shown in Figure 16.

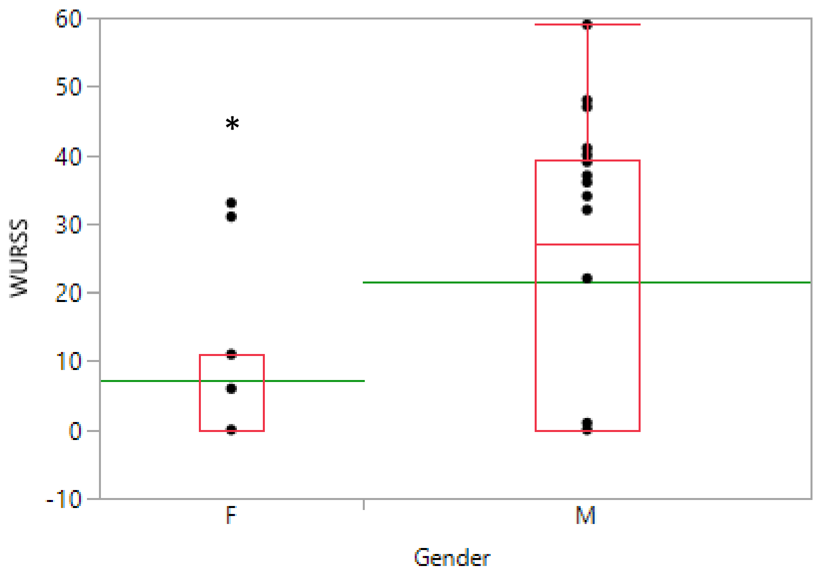

Figure 16. Gender Effect on WURSS Scores.

WURSS Score data points for each individual according to gender with box plots and mean lines (Green) for each gender. * corresponds to a p<0.05.

The DALDA questionnaire had a positive trend with race times and DALDA answer score for A selections (correlation = 0.30, p = 0.0895), which can be viewed in Figure 17. Sleep time and sleep efficacy the night before performing a time trial did not have any significant trends, although there was a positive correlation (correlation = 0.32, p = 0.0669) between PSQI scores and race times. On the AD-ACL there was a significant difference between genders and tired scoring on the AD-ACL (p = 0.007), with females having a significantly lower tired score. Females also scored significantly lower on the tension score of the AD-ACL (p = 0.0023). The actigraphy sleep data did not associate well with the PSQI scores. Sleep efficacy and PSQI had a correlation of 0.37 (p = 0.0012) showing a significant positive trend with higher sleep efficacy leading to higher PSQI scores shown in Figure 18. Sleep time and PSQI also had a low correlation of 0.04 (p

= 0.7671) suggesting that either the actigraphy or the PSQI are not good measures of sleep in this population.

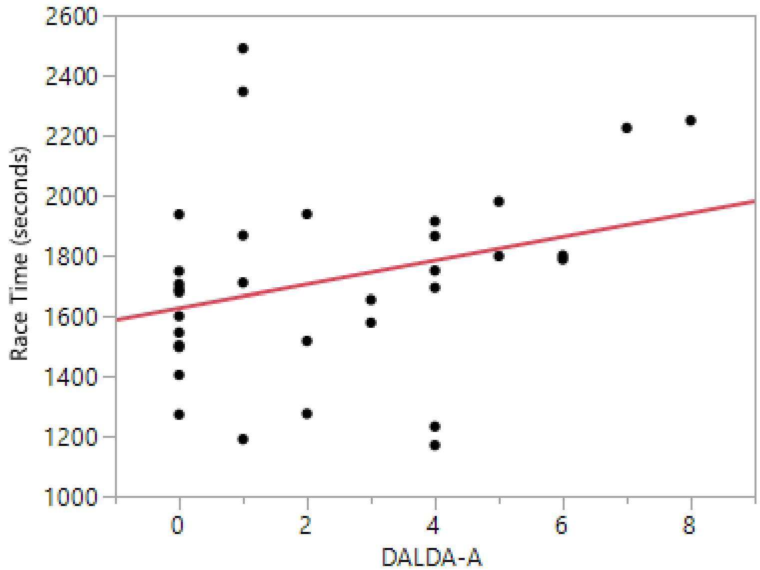

Figure 17. DALDA "Worse than Normal" Scores Effect on Race Time.

DALDA scores for the answer selection A (worse than normal) compared to race time for each individual across all days with trend line (Red). p = 0.0895.

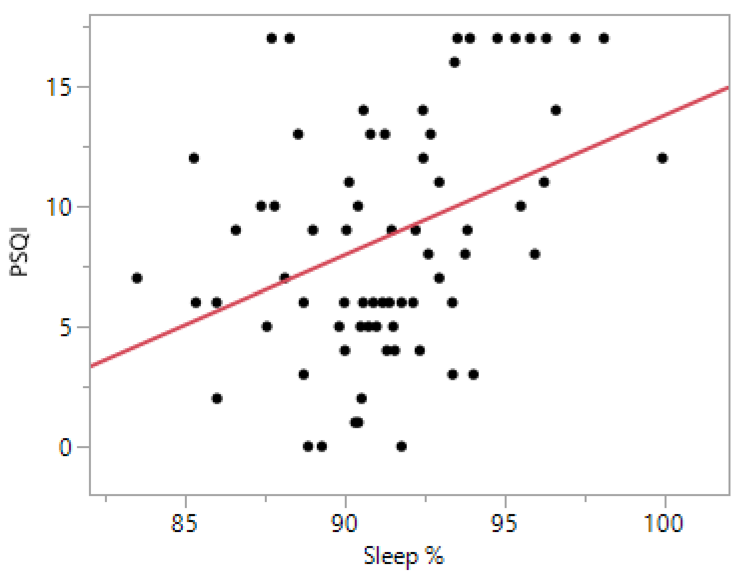

Figure 18. Sleep Efficacy's Effect on PSQI Scores.

Sleep Efficacy data for the participants that wore the actigraphy watches compared to their PSQI scores with a trend line (Red). p = 0.0012

Chapter 5. Discussion

The purpose of this study was to determine whether high school cross-country runners were at risk for hypohydration. Furthermore, this study attempted to characterize the impact of a simple hydration plan on overall hydration status and time trial performance in these athletes. Concerning the findings for SA-1, this population was at risk for being hypohydrated, with USG data showing that this population was defined as being hypohydrated, with 3 of the testing days the participants having an average pre-USG of 1.030 putting the participants at significantly hypohydration [3]. This finding is in alignment with Arnaoutis, Kavouras [8], who also found that high school distance runners were also classified as hypohydrated by USG. These findings also support Rivera-Brown and De Felix-Davila [10] suggestion that high school athletes seem to be in a persistent state of hypohydration with our findings showing that the athletes are hypohydrated persistently over two weeks and stayed in a hypohydrated even after a hydration strategy was implemented. This population has many factors accounting towards their hypohydration risk such as School Board Policy of not allowing students to have water bottles in school, not allowing the students readily available access to water during class with only water fountains providing access to water during school hours. According to pre-practice USG data the hydration strategy worked having visit 4 being significantly different from visit 2, which was our control group time trial day. Surprisingly visit 4 was not significantly different from visit 3, although it can be argued that it was practically significant with nearly a 0.006 absolute difference in pre-practice USG with a general downward trend in pre-practice USG. It is also important to note that there was no significant difference between visit 1, visit 2, and visit 3 suggesting that we did not affect the athlete's normal hydration habits or that they changed their hydration habits due to knowledge of being in a hydration study and that a true baseline measure of pre-practice USG was collected, adding to the evidence that our hydration plan was arguably successful.

The objectives of the second specific aim was to identify whether a simple hydration strategy would improve high school athlete's hydration status. The hydration strategy was implemented after visit 3 the only day we have testing the effect of our hydration strategy is visit 4. The data shows that pre-practice USG on visit 4 was significantly lower than visit 1 and most importantly visit 2 suggesting the hydration strategy was enough to improve athlete's hydration status, although the athletes did not reach normal hydration status, there is a possibility that if the hydration strategy was implemented for a longer period normal hydration may have been reached. Although visit 4 was not significantly lower than visit 3 as previously stated an argument can be made that there was practical significance to the change in pre-practice USG. Additionally, a lower pre-practice USG had a significant effect on having lower post-practice USG as seen in Figure 13. A significant difference between core temperatures between our control group time trial day and hydration time trial day was not found, however there were smaller changes from pre to post core temperature in the control group suggesting

that the hydration strategy did not affect core temperature contradictory to past research [12, 30]. This data supports the findings of Magal, Cain [6] who found that a simple hydration strategy was enough to have significant improvements in hydration strategy in division 3 athletes. Our findings along with Magal, Cain [6] suggests that simple hydration strategies can work at multiple levels of competition at improving hydration status, although there is a need for further research to determine the length of time it takes for simple hydration strategies to lower population from significantly at risk for hypohydration to normal hydration status.

Finally, in line with the study's second specific aim was to determine if by improving the athlete's hydration status would lead to an improvement in performance. There was a significant difference in visit 1 compared to all other days with no other significant differences this would suggest that USG pre was not a good predictor of performance. This suggestion that pre-practice USG did not predict race time is further supported by Figure 15 showing no to very little correlation between the two measures. These finding are in contradiction with other studies showing a strong relationship between improving hydration status and performance improvement especially in runners [12, 13]. Although the weather could have affected the race time data as the last time trial day was much colder than the other testing days, with wind chill temperatures on day 4 being 8.3 degrees Celsius (47^{o} Fahrenheit) as visit 1 through 3 were 22.3 (72^{o} Fahrenheit), 20.1 (68^{o} Fahrenheit), and 26.7 (80^{o} Fahrenheit) degree Celsius respectively. This large change in temperature may account for the slower race times on visit 4 and may explain why similar results as past studies [12, 13] were not observed. Interestingly though when the change in pre-practice USG was compared to the change in race times for visit 2 and visit 4, there was a significant effect of change in pre-practice USG to changes in race times, with lowering pre-practice USG having a trend towards lowering race times supporting our second specific aim. It can be hypothesized that this, trend would have been significantly different if the study had a longer hydration period to further see if there would be lower pre-practice USG and race times although due to time restricts with the team's season this was not possible. Having found that that the trend in changes in pre-practice with changes in race times this data would support Casa [12] and Stearns [13] finds that improving hydration status will lead to fast race times. We did find a significant difference in race times between male and females, with males having faster race time, however no other measure had a significant effect due to gender. Additionally, an interesting trend was found with race time being associated with high WURSS scores suggesting that during episodes of upper respiratory illness the athletes perform better, another suggestion could have been that the WURSS is not a valid way to measure upper respiratory symptoms in this population. However, an argument can be made that the participants did not fully understand how to complete the questionnaire suggesting that clearer and more concise instructions were needed. Interestingly, there was also a positive trend between DALDA answer selection A "worse than normal" and race times with high answer A selection being associated with race times. The DALDA questionnaire is

used to determine the athlete's mood and feelings on day to day activities including sport specific questions, with answer selection A being "worse than normal" suggesting the athletes is stressed or not in the mood to perform or complete every day or sport specific tasks. This finding suggests that the DALDA may be an effective way to measure how the athletes feels for that day and may indicate how well they may perform and can be an easy longer-term measurement to assess athlete's mood and stress levels. Lastly, there was a significant effect of sleep efficacy recorded by the actigraph and the participants PSQI scores with higher sleep efficacy trending toward high PSQI scores. The PSQI monitoring sleep quality would suggest that sleep efficacy would have a strong correlation as they measure very similar factors, but this was not observed during the study. This finding is contradictory to past studies [56] and hurts the reliability of the PSQI to monitor sleep quality in this population as the PSQI has lower scores for better quality of sleep, which should correlate to higher sleep efficacy. However this data is collect through self-reported questionnaires and some studies have shown that in this adolescent population that self-report surveys and questionnaires can be inaccurate and invalid, especially in the school setting [60].

There are many limitations to this study, including the low number of participants, which could explain the reduced interpretability of the questionnaire data presented in this thesis. Furthermore, several of the athletes were dual athletes during the study, with one dropping out during the second week due to commitments to their second sport. Finally, low temperatures on the last time trial day (day 4) could have affected the runner's ability to perform with wind chill temperature as low as 8.3 degrees Celsius (47^{o} Fahrenheit).

Chapter 6. Conclusion

We have found powerful evidence that a problem exists in rural school communities with school policies that do not allow for student to bring water bottles to school which puts students at risk for hypohydration especially populations at high risk such as high school athletes. The pre-USG data supports the claim that high school cross-country runners are not only at risk, but at significant risk for hypohydration. This growing evidence should be of concern to coaches at the high school level of competition as being hypohydrated has negative effects on performance and cognitive function. The findings also support that simple hydrations plans improve hydration status in high school athletes. The simple plan of having athletes drink 32 oz. of water with breakfast and dinner was enough to significantly change their hydration status according to USG. There was a significant change in hydration status and USG in the athletes, these changes were associated with an improvement in performance as evident by Figure 7.

In conclusion high school cross-country runners are at risk significant risk for hypohydration, and a simple hydration plan can improve hydration status of the runners, and performance improvements were seen with changes in pre-practice USG and changes in race times.

Appendix. Questionnaires and IRB Approval

DALDA Questionnaire

Monitors state of well being and mood state

(a = worse than normal, b = normal, c = better than normal)

Part A

1.	a	b	c	Diet
2.	a	b	c	Home Life
3.	a	b	c	School/college/work
4.	a	b	c	Friends
5.	a	b	c	Sports Training
6.	a	b	c	Climate
7.	a	b	c	Sleep
8.	a	b	c	Recreation
9.	a	b	c	Health

Part B

1.	a	b	c	Muscle Pains
2.	a	b	c	Techniques
3.	a	b	c	Tiredness
4.	a	b	c	Need for rest
5.	a	b	c	Supplementary Work
6.	a	b	c	Boredom
7.	a	b	c	Recovery Time
8.	a	b	c	Irritability
9.	a	b	c	Weight
10.	a	b	c	Throat
11.	a	b	c	Internal
12.	a	b	c	Unexplained aches
13.	a	b	c	Technique Strength
14.	a	b	c	Enough Sleep
15.	a	b	c	Between Session Recovery
16.	a	b	c	General Weakness
17.	a	b	c	Interest
18.	a	b	c	Arguments
19.	a	b	c	Skin Rashes
20.	a	b	c	Congestion
21.	a	b	c	Training Effort
22.	a	b	c	Temper
23.	a	b	c	Swelling
24.	a	b	c	Likability
25.	a	b	c	Runny Nose

Name____ Date________

Sleep Quality Assessment (PSQI)

What is PSQI, and what is it measuring?

The Pittsburgh Sleep Quality Index (PSQI) is an effective instrument used to measure the quality and patterns of sleep in adults differentiates "poor" from "good" sleep quality by measuring seven areas (components): subjective sleep quality, sleep latency, duration, habitual sleep efficiency, sleep disturbances, use of sleeping medications, and daytime dysfunction over the last montl

INSTRUCTIONS:

The following questions relate to your usual sleep habits during the past month only. Your answers should indicate the most accurate reply for the majority of days and nights in the past month. Please answer all questions.

During the past month,

1. When have you usually gone to bed? ____________________
2. How long (in minutes) has it taken you to fall asleep each night? ____________________
3. What time have you usually gotten up in the morning? ____________________
4. A. How many hours of actual sleep did you get at night? ____________________
   B. How many hours were you in bed? ____________________

5. During the past month, how often have you had trouble sleeping because you	Not during the past month (0)	Less than once a week (1)	Once or twice a week (2)	Three or more times a week (3)
A. Cannot get to sleep within 30 minutes				
B. Wake up in the middle of the night or early morning				
C. Have to get up to use the bathroom				
D. Cannot breathe comfortably				
E. Cough or snore loudly				
F. Feel too cold				
G. Feel too hot				
H. Have bad dreams				
I. Have pain				
J. Other reason (s), please describe, including how often you have had trouble sleeping because of this reason (s):				
6. During the past month, how often have you taken medicine (prescribed or "over the counter") to help you sleep?				
7. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?				
8. During the past month, how much of a problem has it been for you to keep up enthusiasm to get things done?				
9. During the past month, how would you rate your sleep quality overall?	Very good (0)	Fairly good (1)	Fairly bad (2)	Very bad (3)

Wisconsin Upper Respiratory Symptom Survey – 21 --- *Daily Symptom Report*

Day:	*Date:*	*Time:*	*ID:*

Please fill in one circle for each of the following items:

	Not sick	Very mildly		Mildly		Moderately		Severely
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
How sick do you feel today?	O	O	O	O	O	O	O	O

Please rate the average severity of your cold symptoms over the last 24 hours for each symptom:

	Do not have this symptom	Very mild		Mild		Moderate		Severe
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Runny nose	O	O	O	O	O	O	O	O
Plugged nose	O	O	O	O	O	O	O	O
Sneezing	O	O	O	O	O	O	O	O
Sore throat	O	O	O	O	O	O	O	O
Scratchy throat	O	O	O	O	O	O	O	O
Cough	O	O	O	O	O	O	O	O
Hoarseness	O	O	O	O	O	O	O	O
Head congestion	O	O	O	O	O	O	O	O
Chest congestion	O	O	O	O	O	O	O	O
Feeling tired	O	O	O	O	O	O	O	O

Over the last 24 hours, how much has your cold interfered with your ability to:

	Not at all	Very mildly		Mildly		Moderately		Severely
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Think clearly	O	O	O	O	O	O	O	O
Sleep well	O	O	O	O	O	O	O	O
Breathe easily	O	O	O	O	O	O	O	O
Walk, climb stairs, exercise	O	O	O	O	O	O	O	O
Accomplish daily activities	O	O	O	O	O	O	O	O
Work outside the home	O	O	O	O	O	O	O	O
Work inside the home	O	O	O	O	O	O	O	O
Interact with others	O	O	O	O	O	O	O	O
Live your personal life	O	O	O	O	O	O	O	O

Compared to yesterday, I feel that my cold is…

Very much better	Somewhat better	A little better	The same	A little worse	Somewhat worse	Very much worse
O	O	O	O	O	O	O

Self-Assessment Inventory

INSTRUCTIONS: Following are some adjectives that describe people's feelings. Please, read each of the adjectives and then indicate how you are feeling *at this particular moment*, by circling the appropriate response. There are no right or wrong answers, so do not spend too much time on any one item. Check to make sure you have responded to all the items.

	Definitely feel	Feel slightly	Cannot decide	Definitely do not feel
1. Active	++	+	?	no
2. Placid	++	+	?	no
3. Sleepy	++	+	?	no
4. Jittery	++	+	?	no
5. Energetic	++	+	?	no
6. Intense	++	+	?	no
7. Calm	++	+	?	no
8. Tired	++	+	?	no
9. Vigorous	++	+	?	no
10. At rest	++	+	?	no
11. Drowsy	++	+	?	no
12. Fearful	++	+	?	no
13. Lively	++	+	?	no
14. Still	++	+	?	no
15. Wide-awake	++	+	?	no
16. Clutched-up	++	+	?	no
17. Quiet	++	+	?	no
18. Full-of-pep	++	+	?	no
19. Tense	++	+	?	no
20. Wakeful	++	+	?	no

Thayer (1989)

ACTION ON PROTOCOL APPROVAL REQUEST

Institutional Review Board
Dr. Dennis Landin, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
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TO: Guillaume Spielmann
Kinesiology

FROM: Dennis Landin
Chair, Institutional Review Board

DATE: October 19, 2018

RE: IRB# 4123

TITLE: Influence of Hydration Status on Running Performance and Marker of Psychological and Physiological Stress in High School Cross-Country Runners

New Protocol/Modification/Continuation: New Protocol

Review type: Full ____ Expedited X **Review date:** 10/17/2018

Risk Factor: Minimal X Uncertain ______ Greater Than Minimal _______

Approved X **Disapproved** __________

Approval Date: 10/19/2018 **Approval Expiration Date:** 10/18/2019

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 20

LSU Proposal Number (if applicable):

By: Dennis Landin, Chairman DLandin

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants, including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. **SPECIAL NOTE: When emailing more than one recipient, make sure you use bcc.**

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.lsu.edu/irb*

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Vita

Joshua Aaron Granger was born in Mamou, Louisiana. He studied Kinesiology at Louisiana State University. After earning his bachelor's degree in 2017, he came back for his master's degree in Exercise Physiology. His fascination in sports training and sports research, specifically in high school athletes grew as he began research in LSU's Exercise Physiology Lab. After earning his master's degree, he plans to attend LSU for his Ph.D. in Exercise Physiology.