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Player-Reported Fluid Intake & Measured Hydration Status of NCAA Division I
Football Athletes During Fall Training Camp

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Abstract

Player-Reported Fluid Intake & Measured Hydration Status of NCAA Division I Football Athletes During Fall Training Camp

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Background:

Hydration is critical to the health and sports performance of athletes. Position statements from the American College of Sports Medicine, the National Athletic Trainers' Association, and the Academy of Nutrition and Dietetics include recommendations for adequate fluid intake to prevent dehydration. Dehydration is associated with physiologic changes, including increased core body temperature and heart rate that can lead to performance deficits. Decreases in muscle strength can occur at levels of 5% dehydration, and reductions in aerobic power and endurance take place at levels of 3-4% dehydration. Despite the importance of hydration, athletes frequently participate in training or competition in a dehydrated state.

Methods:

This study was designed to assess the fluid intake, hydration status, and levels of fatigue and muscle soreness among collegiate athletes. The sample consisted of forty-six National Collegiate Athletics Association (NCAA)-Division I (D1) male football athletes at the University of Washington who participated in 2016 fall training camp. The athletes completed a daily survey to report fluid intake (liters) during the previous day, level of muscle soreness (5-point scale), and level of fatigue (5-point scale). Hydration status was assessed using urine specific gravity (USG) testing on three occasions during fall training camp. Hydration status was determined based on the American College of Sports Medicine and National Athletic Trainers' Association

criteria: (1) *euhydrated*, which was urine specific gravity less than 1.020; (2) *hypohydrated*, from 1.020 to 1.029; and (3) *significantly hypohydrated*, equal to or more than 1.030. Player position and year on the team was also recorded for each athlete.

Results:

Fluid intake (L/day) and USG of the football athletes were suggestive of appropriate hydration strategies and adequate hydration levels during fall training camp. 81.1% of athletes had fluid intake levels above 3.7 liters of fluid per day ($p < 0.001$), and 64.9% of athletes had urine specific gravity (USG) below 1.020 ($p < 0.0001$), indicating a state of hydration. USG was found to be significantly inversely associated with fluid intake. Mean urine specific gravity was lower for athletes with higher fluid intake ($R^2 = -0.0019$, $p < 0.0001$). Player position or year on the team was not associated with fluid intake (L/day) or USG. Muscle soreness and fatigue (5-point scale) were found to be positively associated with USG, with marginal ($p=0.064$) significance and statistical significance ($p=0.019$), respectively. Levels of fatigue and muscle soreness increased as USG increased, suggesting more severe fatigue and soreness in states of hypohydration.

Conclusion:

American football athletes are at increased risk for dehydration due to high sweat rates, heavy protective equipment, conditions of heat or humidity during training, and often large body mass. Although athletes face this risk, athletes can maintain a state of hydration with adequate fluid intake. 64.9% of all athletes in this study were hydrated, and no athletes were found to be in a state of severe dehydration. Daily fluid intake of athletes (M=5.0 L, SD=0.9 L), which was above the AI recommendation, may have been at a level sufficient to maintain hydration. Athletes with higher urine specific gravity (USG), indicating lower level of hydration, were found to have higher levels of muscle soreness and fatigue. Increased education on hydration and more frequent monitoring of hydration status is essential to reducing risk of dehydration and its associated consequences for athlete health and performance.

1. INTRODUCTION

Hydration is critical to the health and sports performance of all athletes. Maintenance of fluid balance during exercise has been considered as one of the most important factors associated with sustaining a high level of athletic performance (Benardot, 2006). Monitoring hydration status and maintaining an appropriate level of hydration is especially important for American collegiate football players who play in conditions of heat while wearing heavily padded equipment during fall training camp, which typically occurs at the end of summer (Judge et al., 2016). Position statements of the International Society of Sports Nutrition (ISSN) (Kreider et al., 2010), American College of Sports Medicine (ACSM) (Sawka et al., 2007), the National Athletic Trainers' Association (NATA) (Casa et al., 2000), and the Academy of Nutrition and Dietetics (AND) (Sawka, 2005) indicate that athletes need adequate fluid intake before, during, and after exercise to avoid hypohydration and meet the physical demands of performance.

The goal for an athlete is to be euhydrated before, during, and after exercise to prevent negative performance-related impacts due to body water loss and resulting hypohydration (Rodriguez, DiMarco, & Langley, 2009). But, unfortunately, many athletes begin practice or competition in a hypohydrated state and any attempt to “catch up” is often unsuccessful (Sawka et al., 2007). Collegiate football athletes participate in repetitive strenuous exercise, including both sport training and competition and strength and conditioning sessions, which may make it difficult for athletes to maintain appropriate levels of hydration. When total body water (TBW) decreases in an amount greater than two percent of body weight, a state of dehydration occurs, causing changes in physiological function that can lead to detriments in health and athletic performance (Sawka et al., 2007).

1.1 Impacts of Dehydration on Performance and Safety

Water is the primary component of blood, which delivers oxygen, nutrients, hormones, and other substances to cells and removes metabolic by-products from cells (Benardot, 2006). Water also is protective, through its role in cushioning the spinal cord and brain from impact injuries, and is an essential component of the body's temperature regulation mechanism (Benardot, 2006). Under normal conditions, the body is able to regulate blood volume effectively and can account for variations in fluid and sodium intake (Benardot, 2006). During exercise, the body releases hormones that help to conserve sodium and body water. However, exercise at high intensity or of long duration, especially in hot or humid environments, can threaten fluid balance homeostasis, performance, and health (Cheuvront, Carter, & Sawka, 2003). In these conditions, athletes are at risk for dehydration since fluid losses through sweat may exceed athletes' ability to consume and absorb sufficient fluid to replace losses.

Adequate total body water content is necessary to maintain sweat rates during exercise, so that heat can be dissipated and the athlete can continue performing the activity. If fluids are not consumed to replace losses and maintain body water stores, necessary amounts of sweat cannot be produced and heat cannot be dissipated. The rise in body temperature during exercise is more pronounced with increasing levels of dehydration; for every 1% loss in body mass due to sweat losses, body temperature increases at a rate of 0.22°C (0.4°F) (Buono & Wall, 2000;

Huggins et al., 2012). Failure to dissipate heat will result in the body overheating and could eventually lead to heatstroke (Benardot, 2006).

Increased thermoregulatory strain with exercise in a dehydrated state is accompanied by increased cardiovascular strain. During prolonged exercise, the body undergoes a cardiovascular drift, where heart rate increases to counterbalance a decrease in stroke volume to maintain cardiac output for continued exercise (Adams & Casa, 2015). The decrease in plasma volume resulting from dehydration causes an increased heart rate to maintain the delivery of oxygen and other substrates necessary for the body's contracting muscles (Montain & Coyle, 1992), further intensifying cardiovascular drift.

The elevation in heart rate, reduction in cardiac output, and decrease in body capacity to dissipate heat associated with dehydration during exercise have consequences for athletic performance. During exercise in the heat, there are increasing demands of blood flow to both the muscles and skin to maintain muscle function and for thermoregulation (Adams & Casa, 2015). With increasing levels of dehydration, the body prioritizes blood flow to the skin surface to dissipate heat, so blood flow to working muscles is lessened due to this competition. A reduction in performance occurs with the reduction in venous pressure and cardiac output necessary to support both the metabolic needs of exercising muscles and thermoregulation (Cheuvront et al., 2003).

Euhydration is the ideal physiological environment for proper body functioning to support movement in physical activity and sports performance (Webb, Salandy, & Beckford, 2016). Hypohydration, in comparison, hinders bodily functioning for physical activity and performance. Exercise and sport performance deficits can occur with dehydration on a magnitude of >2% total body weight (Baker, 2017). Furthermore, weight loss of more than 4% of body weight during exercise may lead to heat illness, heat exhaustion, heat stroke, and possibly death (Kreider et al., 2010).

Current evidence indicates that hypohydration negatively affects endurance exercise performance (Casa et al., 2010), anaerobic/high intensity performance, muscle strength, muscle power (Judelson et al., 2007), and cognition (Grandjean & Grandjean, 2007). Hypohydrated athletes have been shown to have decreased work capacity (Latzka & Montain, 1999; Rivera-Brown & De Félix-Dávila, 2012; Schoffstall et al., 2001), reduced muscle strength (Latzka & Montain, 1999; Rivera-Brown & De Félix-Dávila, 2012; Schoffstall et al., 2001), and impaired athletic and cognitive performance (Rivera-Brown & De Félix-Dávila, 2012). Considering these outcomes, it is critical that athletes consume adequate fluids before, during, and after exercise to prevent hypohydration and maintain appropriate hydration status.

1.2 Prevalence of Dehydration Among Athletes

Previous studies have examined the hydration status and practices of athletes from various sports and competing at various levels. Overall, despite widespread recognition of the performance decrements associated with dehydration, the evidence highlights a high prevalence of hypohydration and inappropriate hydration practices.

To better understand the pre-competition or pre-training hydration practices of athletes, several studies have used assessment tools, such as urine concentration or urine specific gravity, to determine athletes' hydration status. Maughan et al. showed that 11 of 31 football athletes had pre-game urine osmolality of >900 mOsm/kg, indicating dehydration (Maughan, Shirreffs, & Leiper, 2007). Osterberg et al. reported that roughly half of a group of NBA basketball athletes

had pre-game urine specific gravity (USG) values above 1.020, again showing dehydration (Osterberg, Horswill, & Baker, 2009). Volpe et al. found that 66% of male and female collegiate athletes from a variety of sports had pre-competition USG values suggesting dehydration (Volpe, Poule, & Bland, 2009).

The reported high prevalence of dehydration among athletes, particularly collegiate athletes, may be attributed to a lack of knowledge and understanding of proper hydration practices. Nichols et al. (2005) found that athletes lack adequate knowledge on pre-activity hydration strategies. This finding was further supported by Volpe et al. (2009) who demonstrated that 70% of collegiate athletes were hypohydrated prior to practice. Most recently, Judge et al. (2016) reported that only 24% of National Collegiate Athletics Association (NCAA) Division I (DI) athletes reported drinking enough fluids before, during, immediately after, and two hours post-practice.

The hydration practices of American football athletes specifically have been examined in prior research. Overall, research has indicated that most football players, at all levels, are in a state of persistent fluid deficit (Godek et al. 2005; Stover et al., 2006). Godek et al. (2008) showed that in collegiate and professional football players, average sweat rates among players ranged from 1.6-2.3 L/hr and rates varied according to position. Linemen were found to produce greater sweat rates than the backs (Godek et al., 2008). When hydration status of the athletes was monitored over multiple days of consecutive training, the football players were reported to be unable to replace the necessary fluids during practice and in recovery to return to normal baseline hydration levels (Godek et al., 2008). Stover et al. (2006) suggested that the players' inability to restore fluid levels and maintain appropriate hydration status may be explained by high fluid losses experienced by the players during practice, the inability to replace these large fluid losses during and between practices, and poor hydration practices outside of practice.

Preventing dehydration during exercise is one of the most effective ways to maintain exercise capacity and promote optimal performance (Kreider et al., 2010). The lack of proper hydration practices among athletes that has been reported in the literature, particularly in football players, raises concern for athlete performance as well as health and safety.

1.3 Monitoring and Assessing Hydration Status

Monitoring hydration status of athletes is beneficial in minimizing health risks and complications associated with dehydration, but also in maximizing performance during training and competition. However, there are several ways to evaluate hydrations status, and a lack of consensus on the gold standard method of assessment exists (Armstrong, 2007).

Total body water value, in combination with a plasma osmolality measurement, has been suggested as the most accurate and reliable under controlled laboratory conditions when body fluids are equilibrated (Armstrong, 2007). In the field, easy-to-use and simpler techniques are needed, so body mass change, urine specific gravity, 24-hour urine volume, urine color, and thirst are often preferred. During daily activities, body weight change is considered the quickest, simplest, and most accurate technique (Armstrong, 2007).

The American College of Sports Medicine position statement recommends use of urine specific gravity or urine osmolality. Urine osmolality of 700 mOsmol/kg or a urine specific gravity of 1.020 g/mL can be used as an index of euhydration (Sawka et al., 2007).

1.4 Fluid Intake Needs and Recommendations

There is a lack of universal agreement on a general hydration protocol for athletes and it is difficult to establish recommendations that would meet the needs of all athletes, primarily due to the variable nature of fluid needs (Adams & Casa, 2015). Sweat rate and composition depends on the ambient temperature, humidity, and exercise intensity, but can also vary significantly between individuals (Shirreffs, Sawka, & Stone, 2006).

Humans lose an average of 2.5 L of fluid per day, but in athletes, sweat losses are greater due to the demands of high-level exercise. Data suggests that individual sweat rates can range from 0.5 to 2.0 L/h (Sawka et al., 2007). High mean sweating rates have been reported in American Football (0.6–2.9 L/h), with the large body size of players partially responsible (Buresh et al. 2005; Baker et al. 2015; Godek et al. 2008, 2010) as well as the equipment/uniform requirements (Armstrong et al. 2010). Even within football athletes as a group, sweat rates has been shown to differ, notably by player position (Godek et al. 2010). Linemen were shown to have higher sweat rates when compared to the backs (Godek et al. 2008). Since fluid losses are so variable, applying generalized estimates or averages of sweat rates from the literature is unlikely to appropriately meet an individual fluid needs (Casa et al., 2000). Calculation of an individual athlete's sweat rate is necessary to establish individual fluid needs and develop personalized hydration strategies.

Standardized or fixed recommendations for fluid intake prior to exercise or training may not be appropriate and sufficient for individual athletes. General guidelines can cause harm in athletes with sweat rates on the high end or low end of the range. With general guidelines, for athletes with low sweat rates, the risk for exertional hyponatremia is large, whereas for athletes with high sweat rates, following general recommendations may not allow for restoration of fluid losses during exercise (Godek et al., 2005). Instead, fluid intake protocols may need to be more personalized, calculating fluid needs according to individual sweat rate and composition. The most recent position statement from the American College of Sports Medicine (Sawka et al., 2007) recommends fluid intake during prolonged exercise in amounts sufficient in limiting any body mass loss to <2% of the pre-exercise mass.

It's recommended that athletes try to minimize their fluid losses by drinking fluids ad libitum during exercise and replacing fluid losses after activity in order to maximize potential for optimal performance (Adams & Casa, 2015). Recommendations also suggest that coaches and medical personnel make modifications to practices or training schedules that allow for more rest breaks for hydration according to the amount of protective equipment worn and the environmental conditions of the practice (Adams & Casa, 2015).

1.5 Addressing Gaps in the Literature

The existing literature highlights a widespread lack of understanding of the importance of hydration and proper hydration practices among athletes, and underlines the need for increased nutrition education and support of proper hydration. The present study adds to the literature and further describes hydration status and practices of collegiate football athletes. The purpose of the study is to address fluid intake and hydration of NCAA Division I football athletes during fall training camp. The study specifically aims to consider the degree of association between player-reported fluid intake and measured hydration status using urine specific gravity (USG), assess adequacy of fluid intake in maintaining euhydration, and consider the association of hydration status with muscle soreness and fatigue.

2. METHODS

The present study is a secondary analysis of information collected from University of Washington football athletes during fall training camp in 2016. Data were initially collected for internal monitoring of athletes' health and performance; the data were not initially collected for analysis or for the purposes of this study. The football program has given permission for use of the data for secondary analysis. Since the data were not originally collected for research purposes and all data were de-identified, IRB approval was not required.

2.1 Participants

Data were collected from forty-five National Collegiate Athletics Association (NCAA) Division I (D1) male football athletes at the University of Washington during fall training camp in 2016. The forty-five athletes from which data were collected were existing participants in the team's Catapult™ program run by the Strength and Conditioning Department, in which data are collected for internal monitoring of health and performance of athletes. Initial athlete selection criteria for inclusion into the Catapult™ program was not disclosed. All athletes participating in the Catapult™ program (n = 45) were included in this study. Data were de-identified for safety and privacy purposes. Each athlete was assigned a three-character random alphanumeric identifier in replacement of athlete names. A database containing strictly de-identified data was used for research purposes in this study.

2.2 Procedures

Data on hydration status determined by urine specific gravity, player-reported fluid intake, player-reported level of muscle soreness, and player-reported level of fatigue were collected from the forty-five athletes during the three-week fall training camp in 2016.

2.2.1 Assessment of Hydration Status Using Urine Specific Gravity (USG)

Hydration status of athletes was determined by urine specific gravity (USG) and was based on a scale published by the American College of Sports Medicine (ACSM) and the National Athletic Training Association (NATA) (Casa et al., 2000; Sawka et al., 2007). This scale has been used in similar studies previously (Volpe et al., 2009). Urine samples used for USG testing were the first morning void. Urine concentration in first morning urine excretion is sufficiently sensitive to detect deviations in fluid balance (Sawka et al., 2007) and is not affected by acute fluid ingestion (Oppliger, Magnes, Popowski, & Gisolfi, 2005). Hydration status was divided into three categories: euhydration defined as USG between 1.000 and 1.020; hypohydration defined as USG between 1.021 and 1.029; and significant hypohydration defined as USG of 1.030 or greater.

Urine specific gravity (USG) testing was conducted at three time points during the three-week fall training camp period (8/8/16, 8/12/16, 8/17/16). On the days when USG testing was conducted, the first morning void urine sample was collected from each athlete. Each athlete was informed of the planned testing the day prior and instructed to complete the first morning void at the football facilities to provide a urine sample in the specimen cup. Upon entrance into the

football facilities in the morning, each athlete was provided a specimen cup and instructed to provide a urine sample in the cup. The samples were analyzed for USG using a refractometer (Atago 3730 Pen-Pro) within thirty minutes of specimen collection. Between sample readings, the refractometer was sanitized using Kimwipes and zeroed. To reduce the risk of error, a group of four Sports Nutrition interns were trained in assessment and conducted all analyses. One trained intern would test urine samples for USG by dipping the tip of the refractometer into the urine in the specimen cup, and another trained intern would record the result from testing into an excel spreadsheet.

The existing literature suggests that total body water in combination with plasma osmolality provides the “gold standard” for the assessment of hydration (Oppliger et al., 2005). However, in the present study, where a large number of athletes were tested prior to practice, USG provided an economical, practical, and sensitive tool in the assessment of acute hydration status.

2.2.2 Survey to Assess Player-Reported Fluid Intake, Fatigue, and Muscle Soreness

Survey data on player-reported fluid intake, player-reported fatigue, and player-reported muscle soreness were collected daily during the three-week fall training camp period. The survey instrument, titled the “Readiness Questionnaire”, was created and developed by the football Assistant Strength and Conditioning coaches and was already in use for the internal monitoring of athlete performance and health through the Catapult™ program. The survey data collected by the Assistant Strength and Conditioning coaches were de-identified and shared for use in this study.

The seven-item survey collects information on player-reported fluid intake and player-reported ratings of muscle soreness and fatigue. Two items on the survey require written responses by the athlete: sleep duration (number of hours the previous night) and hydration (liters of fluid consumed in the previous day). Five items on the survey require responses using a 5-point scale: fatigue, sleep quality, general muscle soreness, stress level, and mood. Athletes rate each category on a 5-point scale, with 5 being the ideal state for each and 1 being the poor state for each, and with each number given a descriptor to assist the athletes in identifying an accurate ranking. For example, general muscle soreness could be reported as 5 (feeling great), 4 (feeling good), 3 (normal), 2 (increased in soreness/tightness), 1 (very sore). Fatigue could be reported as 5 (very fresh), 4 (fresh), 3 (normal), 2 (more tired than usual), 1 (always tired).

The survey is in an electronic format for ease of distribution to athletes and efficiency in collecting and recording information. During the three-week training camp period, the survey was distributed on an iPad to the athletes every morning, by the Strength and Conditioning coaches, immediately as each athlete entered the football complex. The purpose of the survey was explained to each athlete prior to the start of training camp, and consent for collection of survey data was obtained. Completion of the survey took athletes approximately five minutes. Collected survey data were saved and stored in a secure file under the discretion of the Strength and Conditioning staff.

2.3 Statistical Analysis

Data analysis was conducted using Stata (StataCorp. 2015. *Stata Statistical Software Release 14*. College Station, TX: StataCorp LP). Descriptive statistics are displayed by USG

level categories (euhydrated, hypohydrated, significantly hypohydrated, missing), as well as for the entire sample. For each athlete, three samples were collected at three different times. For descriptive purposes, data collected at three different times are considered three separate observations. Athletes with missing values were included in the model, but missing values were excluded from analyses.

Means and standard deviations were calculated to describe continuous variables. Frequencies and percentages were calculated to describe discrete variables. A scatter plot is presented to show fluid intake against USG level, together with a loess curve to describe overall trend of USG against fluid intake. A “spaghetti plot” is also presented, showing USG plotted against time with athlete measurements connected using a curve, to illustrate the trend of USG over three time points for each athlete.

Generalized Estimating Equation (GEE) linear regression model was used to assess the association between hydration status (USG) and player-reported fluid intake (L/day). The unadjusted model shows the crude association between fluid intake and USG. An adjusted model was used to consider factors such as years on the team and position to address potential confounding effect or add precision to the results. One sample t-tests were used to examine whether mean fluid intake (L) and USG across all athletes meet current recommendations for daily fluid intake (> 3.7 L/day, AI for men ages 19-30 years) and hydration (USG < 1.020). Linear regression model was used to assess degree of association between fluid intake and players’ year on the team or position on the team. GEE linear regression was also used to assess both the degree of association between USG and player-reported muscle soreness (1-5) and the degree of association between USG and player-reported fatigue (1-5).

3. RESULTS

3.1 Descriptive Statistics (Table 1; Figure 1, Figure 2)

Descriptive statistics displayed by USG level categories (euhydrated, hypohydrated, significantly hypohydrated, missing) are shown in Table 1 (Appendix). A total number of 111 samples were included in this study. Players’ year on the team, fluid intake (L/day), level of fatigue (1-5) and level of muscle soreness are displayed as mean and standard deviation. Player position on the team is displayed as frequency and percent.

USG never exceeded 1.029, indicating no athletes were “significantly hypohydrated” at the three USG testing times during the fall training camp. There was a total of thirty-eight missing USG samples, which were included in the model without imputation, as the generalized estimating equation (GEE) model can accommodate missing values. Average fluid intake among all athletes was 5.0 L/day (SD=1.9 L/day). Mean level of fatigue was 3.4 (5-point scale, SD=0.9) and mean level of muscle soreness was 3.1 (5-point scale, SD=1.0). Average year on the team among athletes was 2.5 (1-4, SD=0.9).

Hypohydrated athletes (USG 1.021-1.029) had a lower mean fluid intake (4.1 L/day) than euhydrated athletes’ (USG 1.000-1.020) mean fluid intake (6.2 L/day). Fluid intake (L/day) appears inversely associated with USG. No systematic trends for fluid intake (L/day) across time were observed (SD = 0.8 L/day). Hypohydrated athletes (USG 1.021-1.029) also had a higher mean level of fatigue (3.3) and higher mean level of muscle soreness (3.1) than euhydrated athletes’ (USG 1.000-1.020) mean level of fatigue (3.1) and mean level of muscle soreness (2.9).

3.2 Inferential Statistics (Tables 1-6)

Results from the GEE linear regression model adjusting for player position and year on the team (Table 2) shows that mean USG was lower for athletes with higher fluid intake ($R^2 = 0.0019$, $p < 0.0001$). USG level was significantly inversely associated with fluid intake.

Mean fluid intake of 30 athletes (81.1% of all athletes) met the Adequate Intake (AI) value of fluids for men ages 19-30 (IOM, 2004). The test for mean fluid intake over all the athletes showed that mean fluid intake was above 3.7 L/day, and this finding was statistically significant ($p < 0.001$). Mean USG of 24 athletes (64.9% of all athletes) fell below the recommended USG cutoff value indicative of adequate hydration status of 1.020. The test for mean USG over all players showed that mean USG was below 1.020, and this was statistically significant ($p < 0.0001$). The model fitting results indicate that neither player position nor year on the team was associated with fluid intake or USG.

Results from the GEE linear regression model show that muscle soreness and fatigue (5-point scale) were positively associated with USG, with marginal ($p=0.064$) and statistical significance ($p=0.019$), respectively. Levels of fatigue and muscle soreness increased as USG increased, suggesting more severe fatigue and soreness in states of hypohydration.

4. DISCUSSION

The primary purpose of this study was to assess the degree of association between fluid intake and hydration status using urine specific gravity in NCAA Division I football athletes. The secondary aims were (1) to compare fluid intake and hydration status of athletes to recommendations and (2) to assess the relationship of hydration status with muscle soreness and fatigue.

4.1 Summary and Comparison of Findings to the Literature

Results from this study showed a significant association between player-reported fluid intake and USG level, with higher fluid intake associated with increased hydration status. The results also highlighted a relatively low prevalence of dehydration among the athletes, according to urine specific gravity assessment. 64.9% of athletes had an average USG between 1.000-1.020, the range indicating adequate hydration level. This finding of more than half of the athletes being in a hydrated state does not align with previously reported findings in the literature. Prior research investigating the hydration practices of American football athletes has found, for the most part, athletes to be in a persistent state of fluid deficit (Sandra Fowkes Godek et al., 2008; Stover et al., 2006; Yeargin et al., 2010). In this study, it appears that more football athletes were appropriately hydrated as opposed to dehydrated, and athletes were in a state of fluid balance rather than a persistent state of fluid deficit.

The daily fluid intake of athletes was recorded and assessed for adequacy in maintaining appropriate hydration levels. Fluid intake was compared to the IOM's established adequate intake (AI) value for males age 19-30 of 3.7 L/day (IOM, 2004). The AI is based off of population survey data and current research, and the value reflects total water intake from drinking water as well as other beverages containing water and from solid foods (Fink & Mikesky, 2017). In comparison to the AI, most athletes in this study consumed fluids in amounts greater than the AI. 81.1% of the

athletes had fluid intake above 3.7 L/day, with the overall average daily fluid intake being 5.0 liters. It has been suggested that the AI may not be applicable to athletes, as fluid needs of physically active people can often exceed 3-4 liters per day and can even be in excess of 10 liters per day (IOM, 2004). Athletes in this study were consuming above the AI for fluids, with average intake of 5.0 L/day, but fluid intakes were able to effectively meet fluid needs. The finding that more than half of the athletes were appropriately hydrated according to USG implies that daily fluid intake of the athletes was satisfactory in meeting fluid needs to maintain a state of hydration.

An athlete's position on the team or year on the team was not found to be significantly associated with fluid intake or hydration level. This also stands in contrast to the existing literature. Godek et al. (2008) showed significant positional differences in sweat rate and fluid turnover in American football athletes. Within the team, linemen have been shown to have greater risk for dehydration due to their greater body surface area (Godek et al., 2008). Additionally, knowledge of hydration has been shown to vary according to position on the team, with linemen having lowest levels of knowledge (Judge et al., 2016). In this study, we hypothesized that athletes who have been on the team for longer would have greater knowledge of hydration and more experience with hydration practices, and thus, would have higher hydration levels with greater fluid intake, when compared to athletes who are newer to the team with less experience or knowledge. But, the results indicate that neither position nor year on the team is associated with hydration status or fluid intake.

It is well understood that hydration is critical to athletic performance, with worsening levels of dehydration being associated with more severe performance decrements. The effect of hydration on two performance-related factors was analyzed in this study: muscle soreness and fatigue. A significant positive association between USG and fatigue was shown. USG level of hydration was also found to be positively associated with muscle soreness, but with marginal significance. Fatigue and muscle soreness can impact ability to perform optimally, and this may explain performance deficits associated with dehydration discussed in the literature. Previous studies have discovered increased subjective ratings of fatigue and perceived exertion with hypohydration. Nuccio et al. (2017) notes that multiple factors (including core and skin temperature) likely provide afferent inputs for central nervous system integration and reduce motor drive to skeletal muscles.

The effects of dehydration on muscle function and endurance have been considered. Hypohydration has been shown to result in decreased muscle blood flow (González-Alonso et al. 1999) and alterations in skeletal muscle metabolism (increased lactate, muscle glycogenolysis, and carbohydrate oxidation) (González-Alonso et al., 1999; Logan-Sprenger et al., 2013). Symptoms of delayed-onset muscle soreness (DOMS), which describes the sensation of discomfort or pain that is often combined with muscle tenderness, stiffness, and weakness, have been found to be more severe in states of dehydration (Cleary, Sweeney, Kendrick, & Sitler, 2005). While fatigue and soreness are only two considerations in performance, it's evident they may be exacerbated in dehydration to contribute to performance decrements.

4.2 Strengths and Limitations

It is important to recognize the limitations present in this study. First, it must be noted that there were missing data on USG values. Thirty-eight USG values were missing during the training camp period. The missing data were likely due to lack of athlete compliance or adherence to protocol. Athletes may have forgotten to return their specimen cup, already voided and not felt the urge to urinate, or may have felt uncomfortable with providing a urine sample. In

the future, protocols for hydration testing and assessment should be clear and plans for hydration assessment well known, so that similar issues can be avoided.

While the aim of USG hydration testing was to collect the first morning void for assessment, it was difficult to ensure this guideline was followed by athletes. Athletes were provided advanced notice of testing and were given the specimen cup upon entering the facilities first thing in the morning on the day of testing. However, it is possible that some athletes voided prior to entering the facilities. The first morning void (collection of the first urine void after the individual awakes from sleep) is considered the preferred sample for testing. First morning void is considered a more accurate indicator of hydration status as it is not affected by food and beverage consumption and sweat and urinary losses that occur throughout the day (Shirreffs et al., 2006). Future studies using urine specific gravity should make sure to test first morning void samples to ensure results accurately reflect true hydration status.

Urine specific gravity was used to assess hydration status, and USG is generally considered a sensitive indicator of hydration status (Casa et al., 2000). However, if changes in body weight could have also been measured and assessed, interpretation of hydration status would have been more reliable. Changes in body weight can be used to estimate fluid losses by comparing pre- and post- exercise body weight, as well as calculate sweat rate.

Finally, the type and timing of fluid ingestion was not analyzed in this study, which may significantly affect the ability of an individual to remain hydrated or to effectively rehydrate (Sawka et al., 2007). Further research is therefore needed in this area, considering not only quantity, but also quality of fluid consumption in terms of timing and type.

4.3 Practical Application

The existing literature highlights a high prevalence of dehydration among football athletes, particularly during periods of repeated training or exercise in hot and humid conditions, such as during fall training camp. However, results from the present study do not support past findings and instead describe a higher prevalence of adequate hydration than hypohydration among football athletes. More than half of the athletes in this study were adequately hydrated according to USG, and the majority of athletes consumed fluids in levels above the AI of 3.7 L/day. However, the AI was developed to target the general population, so it is not the ideal reference point for fluid intake since athletes typically have much higher fluid needs (Kenney, 2004).

The hydrated state of the athletes included in this study may be explained by a variety of factors, but key considerations include knowledge and awareness of hydration and adequate opportunities for fluid intake. Previous studies have found collegiate football players to have inadequate knowledge regarding proper hydration (Judge et al., 2016; Nichols et al., 2005). The athletes in the present study may have had greater knowledge and understanding of fluid intake and hydration compared to athletes in the past. The presence and level of involvement of athletic staff (particularly sports dietitians, strength coaches, and trainers) in promoting and advocating for sound hydration practices may have been sufficient in encouraging athletes to hydrate. Athletes often consider athletic trainers to be their primary source of information, followed by strength and conditioning coaches and then dietitians (Burns, Schiller, Merrick, & Wolf, 2004). Thus, given the influence they may have on athlete hydration, it is important that the coaches, trainers, and other athletic staff have appropriate understanding of hydration and be aware of their role in improving hydration practices.

Athletes may have been more cognizant of hydration and fluid intake due to the frequency with which hydration status was assessed and monitored during training camp. Athletes also had abundant opportunity during practices to consume fluids; student athletic trainers equipped with ample fluids (bottles of water and PowerAde™) followed individual position groups throughout the duration of each practice.

Providing education to athletes on proper hydration and fluid replacement practices and regularly monitoring fluid levels to reinforce positive behaviors and attitudes is necessary to promote athlete health and performance (Cupisti et al., 2002; Judge et al., 2016; Nichols et al., 2005). Research highlights that knowledge, attitudes, and behaviors of collegiate athletes is important in promoting good hydration practices (Judge et al., 2016). Improving frequency in which athletes have adequate hydration knowledge will help to reduce risk of dehydration and its associated consequences (Cupisti et al., 2002). Monitoring and assessment of athlete hydration should be done frequently and accurately, and this can be most effectively done through the development of assessment protocols. Judge et al. (2016) recommends targeted education on hydration to teach athletes how to improve their hydration levels, maintain health, reach peak performance, and properly recover post-exercise.

Although there were a higher prevalence of hydration and adequate fluid intake among athletes in this study overall, athletes with higher USG, indicating less hydration or dehydration, experienced higher levels of fatigue and muscle soreness. Fatigue and soreness may directly limit an athlete's ability to exercise and participate in sport, especially at an optimal level of performance. Promoting hydration is critical in ensuring athlete health and preventing heat stroke or heat illness, but also in fostering exercise performance and recovery.

4.4 Conclusion

American football athletes are at risk for dehydration due to high sweat rates to aid in thermoregulation. However, this risk is further amplified in preseason training when temperatures and humidity are high, required protective equipment worn by athletes that thwarts heat dissipation during exercise, and the typically large body mass of football athletes (Armstrong et al., 2010; Godek et al., 2008). Previous studies have confirmed American football as a sport with moderate to high dehydration risk due to high prevalence of dehydration among athletes. Dehydration at high levels can lead to heat stroke or heat illness, but even minor dehydration have been shown to impair athletic performance.

The present study aimed to further characterize the risk and prevalence of dehydration in American football athletes and consider the relationship of hydration with fatigue and muscle soreness. Prevalence of dehydration in this study was much lower than previous reports in the literature, but dehydration was associated with higher levels of fatigue and soreness. These findings emphasize the role of hydration in exercise ability and performance. Future studies should focus on further clarifying prevalence and risk of dehydration in American football. Valid, reliable, and sensitive sport-specific protocols should be developed and used to ensure tests can detect small but meaningful differences in performance.

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Table 1: Overall descriptive statistics ¹

		USG			
		Euhydrated (43) ²	Hypohydrated (30) ²	Missing (38) ²	Overall (111) ²
Years (year) ³		2.3 (0.9)	2.5 (0.7)	2.6 (0.9)	2.5 (0.9)
Fluid (L/day)		6.2 (1.9)	4.1 (1.6)	4.2 (1.4)	5.0 (1.9)
Fatigue ⁴		3.1 (0.8)	3.3 (0.8)	3.7 (0.9)	3.4 (0.9)
Soreness ⁴		2.9 (0.9)	3.1 (0.9)	3.4 (1.2)	3.1 (1.0)
Position ⁵	Back	13 (30.2%)	5 (16.7%)	9 (23.7%)	27 (24.3%)
	Lineman	13 (30.2%)	11 (36.7%)	12 (31.6%)	36 (32.4%)
	Linebacker	7 (16.3%)	7 (23.3%)	7 (18.4%)	21 (18.9%)
	Tight End/Wide Receiver	10 (23.2%)	7 (23.3%)	10 (26.3%)	27 (24.3%)

¹: For all the descriptive statistics tables in this report, for discrete variable, we present the frequency (percentage). For continuous variable, we present the mean (standard deviation).

²: The number of samples included in this group.

³: Labeled 1, 2, 3, or 4

⁴: Assessed using a 5-point scale

⁵: Categorical variable

Figure 1: Spaghetti plot for USG level across time (3 USG testing times)

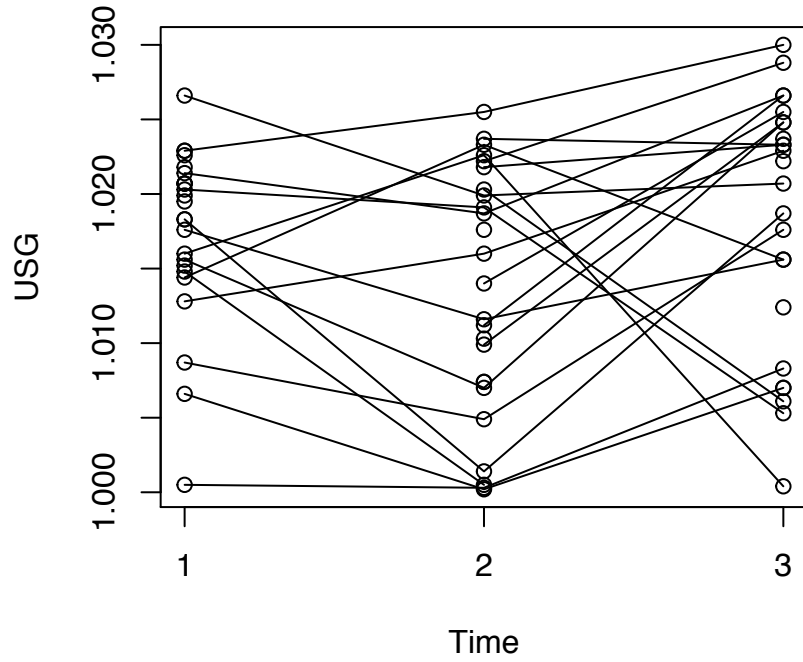
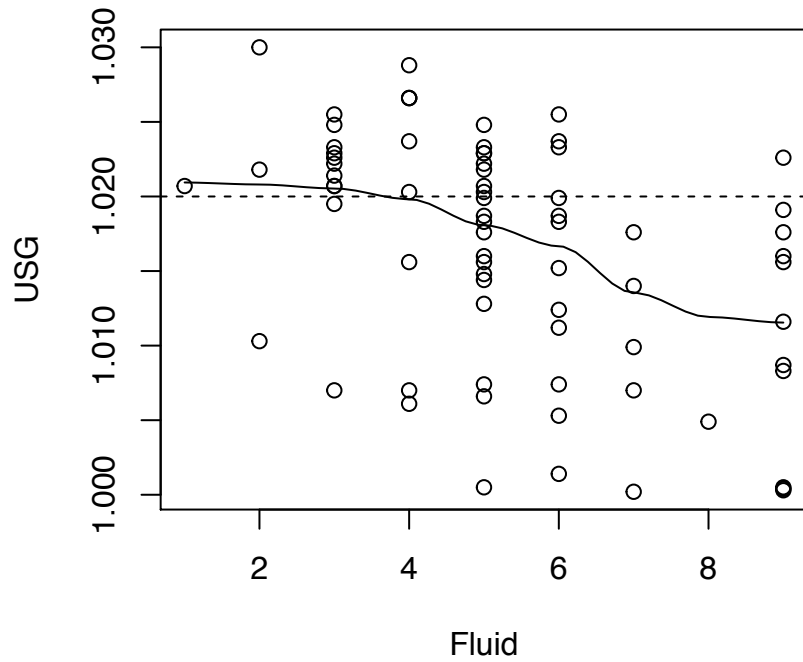


Figure 2: Scatter plot for fluid intake (L/day) against USG level



--- = cutoff between euhydrated (USG 1.000-1.020) and hypohydrated (1.021-1.029).
 — = loess line

Table 2: model fitting results for association between fluid intake and USG level

Model	Covariates	Regression Coefficient	Standard Error	95% Confidence Interval	P-value	
Unadjusted	Fluid intake (L/day)	-0.0018	0.00044	(-0.0026 , -0.00092)	<0.0001	
Adjusted	Fluid intake (L/day)	-0.0019	0.00037	(-0.0027 , -0.0012)	<0.0001	
	Position ¹	Lineman	0.0051	0.0023	(0.00061 , 0.0096)	0.026
		Linebacker	0.0038	0.0024	(-0.001 , 0.0086)	0.12
		Tight End/Wide Receiver	0.0052	0.0023	(0.0007 , 0.0097)	0.024
	Year ²	-0.0011	0.00094	(-0.0029 , 0.00075)	0.25	

¹: Categorical variable

²: Labeled 1, 2, 3, or 4

Table 3: Association between fluid intake and years or position

Covariates		Regression Coefficients	Standard Error	95% Confidence Interval	P-value
Years ¹		-0.026	0.35	(-0.68 , 0.68)	0.99
Position ²	Lineman	0.92	0.79	(-0.63 , 2.5)	0.25
	Linebacker	0.29	0.91	(-1.5 , 2.1)	0.75
	Tight End/Wide Receiver	1.2	0.84	(-0.42 , 2.9)	0.15

¹: Labeled 1, 2, 3, or 4

²: Categorical variable

Table 4: Association between USG and years or position

Covariates		Regression Coefficients	Standard Error	95% Confidence Interval	P-value
Years ¹		-0.0004	0.0012	(-0.0028 , 0.002)	0.75
Position ²	Lineman	0.0015	0.0028	(-0.004 , 0.007)	0.6
	Linebacker	0.0040	0.0032	(-0.0023 , 0.01)	0.22
	Tight End/Wide Receiver	0.0022	0.0030	(-0.0037 , 0.0081)	0.47

¹: Labeled 1, 2, 3, or 4

²: Categorical variable

Table 5: Association between USG level and soreness

Covariates		Regression Coefficients	Standard Error	95% Confidence Interval	P-value
Soreness ¹		0.0017	0.0009	(-0.00009 , 0.0034)	0.064
Years ²		-0.0016	0.0014	(-0.0043 , 0.0011)	0.24
Position ³	Lineman	0.0041	0.0031	(-0.0019 , 0.01)	0.18
	Linebacker	0.0044	0.0029	(-0.0014 , 0.01)	0.14
	Tight End/Wide Receiver	0.0038	0.0027	(-0.0016 , 0.0092)	0.17

¹: Assessed on a 5-point scale

²: Labeled 1, 2, 3, or 4

³: Categorical variable

Table 6: Association between USG level and fatigue

Covariates		Regression Coefficients	Standard Error	95% Confidence Interval	P-value
Fatigue ¹		0.0024	0.001	(0.0004, 0.0044)	0.019
Years ²		-0.0018	0.0014	(-0.0045 , 0.00096)	0.2
Position ³	Lineman	0.0044	0.0028	(-0.0011 , 0.0099)	0.12
	Linebacker	0.0047	0.0027	(-0.00073 , 0.01)	0.09
	Tight End/Wide Receiver	0.003	0.0024	(-0.0016 , 0.0077)	0.2

¹: Assessed on a 5-point scale

²: Labeled 1, 2, 3, or 4

³: Categorical variable